Ciments Canada Lafarge Ltée
Canada Cement Lafarge Ltd.

Energy Conservation in the Industrial Minerals Processing Sector Comminution (Crushing and Grinding) Phase III

Activity 1

Pilot Plant Testing of a
High Efficiency Classifier in a
Conventional Dry Grinding Circuit

WITTECK DEVELOPMENT INC.
2640 South Sheridan Way, Mississauga, Ontario, Canada L5J 2M4
Telephone: (416) 823-7381 Telex: 06-982328

ACTIVITY 1
PILOT PLANT TESTING
OF
A HIGH EFFICIENCY CLASSIFIER
IN A CONVENTIONAL
DRY GRINDING CIRCUIT

ENERGY CONSERVATION
IN THE INDUSTRIAL MINERALS SECTOR
-COMMINUTION-
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606 Cathcart
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H3B 1L7

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Phase III

ACTIVITY I

Pilot Plant Testing of a High Efficiecy Classifier in a Conventional Dry Grinding Circuit

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TABLE OF CONTENTS

		Page No.
1.0	EXECUTIVE SUMMARY	1
	1.1 Objectives	2
	1.2 Description of Testwork	3
	1.3 Results	4
	1.4 Conclusions	7
2.0	INTRODUCTION	8
3.0	OBJECTIVES	12
4.0	METHODOLOGY	13
	4.1 General Discussion	13
	4.2 Description of Equipment	13
	4.2.1 Conical Mill	13
	4.2.2 Gyrotor Classifier	14
	4.2.3 Cyclone Separator	14
	4.2.4 Amvest MS-5 High Efficiency Classifier	15
	4.2.5 Main Exhaust Fan	15
	4.2.6 Dust Collector	15
	4.2.7 Power Measurement	17
	4.2.8 Particle Size Analyzer	17
	4.3 Test Parameters and Procedures	17
	4.3.1 Classifier Selection and Adjustment	17
	4.3.2 Circuit Feed Material	18
	4.3.3 Product Size	20
	4.3.4 Classifier Feed Size and Feed Rate	20
	4.3.5 Airflow and Static Pressures	20
	4.3.6 Sample Receiving	21
	4.3.7 Head Sampling	21
	4.3.8 Mill Circuit Sampling	22
	4.3.9 Screen Analysis and Particle Size Analysis	22
	4.3.10 Clean Up and Disposal	22
	4.3.11 Tromp Curves	23

WD1

TABLE OF CONTENTS (Cont'd)

		Page No.
4.4	Circuit Descriptions and Procedures	25
4.4.1	Test 1	25
4.4.2	Test 2	29
4.4.3	Test 3	33
4.4.4	Test 4	37
4.4.5	Test 5	40
5.0	DISCUSSIONS AND RESULTS	46
5.1	Test 1	46
5.2	Test 2	52
5.3	Test 3	58
5.4	Test 4	65
5.5	Test 5	71
5.6	Dry Brightness Test	78
6.0	CONCLUSIONS	79

APPENDIX I - Test No. 1B Data Sheets
APPENDIX II - Test No. 2 Data Sheets
APPENDIX III - Test No. 3 Data Sheets
APPENDIX IV - Test No. 4 Data Sheets
APPENDIX V - Test No. 5 Data Sheets

LIST OF TABLES

		Page
Table 1.3-T1 -	Activity 1 Representative Production Results	5
Table 4.3.2-T1 -	Steep Rock Calcite	19
Table 4.3.5 -	Typical Static Differential Pressures	21
Table 4.4.1-T1 -	Legend Test 1	27
Table 4.4.2-T1 -	Legend Test 2	31
Table 4.4.3-T1 -	Legend Test 3	35
Table 4.4.4-T1 -	Legend Test 4	38
Table 4.4.5-T1 -	Legend Test 5	41
Table 5.1-T1 -	Test 1 Operating Conditions	46
Table 5.1-T2 -	Test 1 Measured Data	48
Table 5.2-T1 -	Test 2 Operating Conditions	52
Table 5.2-T2 -	Test 2 Measured Data	53
Table 5.3-T1 -	Test 3 Operating Conditions	59
Table 5.3-T2 -	Test 3 Measured Data	61
Table 5.4-T1 -	Test 4 Operating Conditions	65
Table 5.4-T2 -	Test 4 Measured Data	67
Table 5.5-T1 -	Test 5 Operating Conditions	71
Table 5.5-T2 -	Test 5 Measured Data	73

LIST OF FIGURES

		Page
Figure 4.2.4-F1	Amvest MS5 Classifier	16
Figure 4.4.1-F1	Circuit Configuration for Test 1	28
Figure 4.4.2-F1	Circuit Configuration for Test 2	32
Figure 4.4.3-F1	Circuit Configuration for Test 3	36
Figure 4.4.4-F1	Circuit Configuration for Test 4	39
Figure 4.4.5-F1	Circuit Configuration for Test 5	42
Figure 5.1-F1 -	Test 1 Flowsheet	49
Figure 5.1-F2 -	Particle Size Distribution	50
Figure 5.1-F3 -	Tromp Curve	51
Figure 5.2-F1 -	Test 2 Flowsheet	54
Figure 5.2-F2 -	Particle Size Distribution	55
Figure 5.2-F3 -	Tromp Curve	56
Figure 5.3-F1 -	Test 3 Flowsheet	62
Figure 5.3-F2 -	Particle Size Distribution	63
Figure 5.3-F3 -	Tromp Curve	64
Figure 5.4-F1 -	Test 4 Flowsheet	68
Figure 5.4-F2 -	Particle Size Distribution	69
Figure 5.4-F3 -	Tromp Curve	70
Figure 5.5-F1 -	Test 5 Flowsheet	74
Figure 5.5-F2 -	Particle Size Distribution	75
Figure 5.5-F3 -	Tromp Curve	76
Figure 5.5-F4 -	Energy Consumption versus Product Size	77

WD1

1.0 EXECUTIVE SUMMARY

The Department of Energy, Mines and Resources (EMR) CANMET, wishing to assist the industrial minerals processing sector in improving the energy efficiency of its operations and to stimulate R & D, commissioned this study.

The overall objective as stated by EMR was,

> to develop the necessary technology to optimize the comminution of industrial minerals in terms of direct and indirect energy consumption.

Ten industrial minerals were chosen for study and, to achieve the objective, the work was divided by EMR into three phases.

Phase I

> Plant studies to develop a data base.

Phase II

> Establishment of particle size monitoring methodology.
>
> Under this phase, a proposal for pilot plant testing was developed.

Phase III

> Development of pilot plant systems
>
> This report presents description and results of Activity 1 of the pilot plant test programmes.

1.1 Objectives

A pilot scale test programme was operated at Witteck Development Inc. in Mississauga, to examine the performance of a "state of the art" high-efficiency classifier in a conventional dry milling circuit using calcite as a test material. The objectives of the programme were as follows:

- Establish baseline data for a ball mill operated in closed circuit with a conventional classifier to produce a single product;

- Obtain data for a ball mill operated in closed circuit with a high efficiency classifier to produce a single product;

- Obtain data for a ball mill operated in closed circuit with two-stage classification. The conventional classifier was used for primary classification, and the high-efficiency classifier was used for secondary classification handling the product from the primary classifier.

- Obtain data for a ball mill operated in closed circuit with two-stage classification to produce a single product. The conventional classifier was used for primary classification and the high-efficiency classifier was used for secondary classification handling primary reject.

- Obtain data for a ball mill operated in closed circuit with two-stage classification to produce two products. The conventional classifier was used as the primary classifier to produce a 100% minus 45 micron product. The high efficiency classifier, as the secondary classifier, to produce finer products (i.e., 30, 20, 10 microns).

1.2 Description of Testwork

The test programme for Activity 1 consisted of five tests. The circuit configurations used for each test are described as follows:

Test No. 1

The grinding mill was operated in closed circuit with a conventional air classifier operated to produce a single minus 45 micron product collected by a cyclone. Air was bled from the system and passed through a dust collector to collect air entrained fines.

Test No. 2

The grinding mill was operated in closed circuit with a high-efficiency classifier, operated to produce a single minus 45 micron product collected by the air classifier. As in Test 1, some air was bled from the system through a dust collector to collect entrained fines.

Test No. 3

The grinding mill was operated in closed circuit with two stages of classification. The conventional classifier was used as the first stage to produce a coarse cut, containing a minimum of minus 45 micron fines. This product was re-classified with a high efficiency classifier to produce a 45 micron product. Oversize from both classifiers was returned directly to the mill. As in the previous tests, air was bled from the system and passed through a dust collector to collect entrained fines.

Test No. 4

The grinding mill was operated in closed circuit with two stages of classification. The conventional classifier was operated to produce a minus 45 micron product. Rejects from this classifier were re-classified using the high-efficiency classifier to remove the minus 45 micron fines and prevent their return to the mill. As in previous tests, air was bled from the system through a dust collector.

Test No. 5

The grinding mill was operated with two stages of classification. A conventional air classifier was used to produce a minus 45 micron product. A high-efficiency classifier was used to re-classify the fines to produce a finer product, minus 30 microns, then minus 20 microns. Air was bled from the system through a dust collector to collect entrained fines, as in previous tests.

1.3 Results

The representative results from the tests completed during Activity 1 are shown in Table 1.3-T1. It can be seen from the baseline pilot results (Test 1) that the product specification of 95 - 99% passing 45 microns was achieved by the conventional classifier.

Table 1.3-T1

ACTIVITY 1 REPRESENTATIVE PRODUCTION RESULTS

	Test				
	1	2	3	4	5
Production Rate:					
- Total New Feed (kg/hr)	215	392	387	417	160
- Minus 45 Micron Prod(kg/hr)	213	371	376	409	155
Product Size % Passing 45 microns	99.1	94.6	97.2	98.1	-
20 microns					96.8
Unit Power Consumption					
- Total (kwhr/tonne)	95.9	70.0	72.5	62.9	178.1
- Minus 45 microns (kwhr/tonne)	96.9	74.1	74.2	70.2	-
- Minus 20 microns					184.4
Circulating Load					
- Classifier (%)	211	-	211	-	-
- High Effic. Class.(%)	-	162.4	81	-	-
- Total (%)	-	-	292	-	-
Efficiency @ 45 microns (20 microns for Test 5)					
- Classifier (%)	64.5	-	76.7	71.3	87.6*
- High Effic. Class (%)	-	82.6	89.3	87.6	52.4
- Overall (%)	64.5	82.6	70.2	96.3	44.4

Note: Power consumption figures include mill and auxiliary equipment.

* 20 micron product.

By replacing the conventional classifier with a high-efficiency classifier, (comparing Tests 1 versus 2) the following improvements were noted:

- Average power savings in comminution - 25%
- Increase in classification efficiency - 32%
- Increase in production rate - 74%

1016A

The following improvements were noted when a high-efficiency classifier was utilized to re-classify conventional classifier product (Test 1 versus 3).

- Average power savings in comminution - 25%
- Increase in gyrotor efficiency - 18%
- Increase in classification efficiency - 7%
- Increase in production rate - 82%

The following improvements were noted when a high efficiency classifier was utilized to re-classify conventional classifier oversize. (Test 1 versus 4)

- Average power savings in comminution - 27%
- Increase in gyrotor efficiency - 10%
- Increase in classification efficiency - 48%
- Increase in production rate - 92%

Producing both a minus 45 micron product and an ultrafine product (20 microns) with a high-efficiency classifier as in Test 5, may increase power consumption by 75%; increase gyrotor efficiency by 89%, decrease classification efficiency by 38% and decrease production rate by 38% from the baseline data.

Dry Brightness Tests comparing the Ni-hard steel ground calcite versus ceramic ground calcite indicated a slight decrease (0.1 to 0.4%) in brightness for the steel ground product. As brightness testing is beyond the scope of this program, no further testwork was done.

1.4 Conclusions

From these Activity 1 tests, it can be concluded that a high-efficiency classifier, used by itself, or in conjunction with an existing classifer, would use less unit power, require no additional operators or technical support staff, increase production and decrease operating costs.

1.0 RESUME DU PROGRAMME DIRECTEUR

Le centre CANMET du Ministère de l'Energie, des Mines et des Ressources, a commandé cette étude afin de prêter assistance au secteur du traitement des minéraux industriels, dans le but d'améliorer le rendement énergétique de ses exploitations et de stimuler la recherche et le développement.

L'objectif général visé par le ministère est le suivant:

> développer les techniques adéquates afin d'optimiser la pulvérisation des minéraux industriels, en ce qui concerne la consommation directe et indirecte d'énergie.

Dans le cadre de cette étude, on a choisi dix minéraux industriels et, afin de réaliser l'objectif à atteindre, le travail a été divisé en trois phases par le Ministère de l'Energie, des Mines et des Ressources.

Phase I

> Etudes en usine pour développer une base de données.

Phase II

> Mise en place d'une méthodologie du contrôle de la granulométrie des particules.
>
> Dans le cadre de cette phase II, on a réalisé une proposition pour l'essai d'une unité pilote.

Phase III

> Réalisation d'unites pilotes
>
> Ce rapport présente la description et les résultats du plan d'activités no. 1 des programmes d'essais d'unités pilotes.

1.1 Objectifs

Witteck Development Inc. de Mississauga, a conduit un programme d'essais, à l'échelle expérimentale, dans le but d'analyser les résultats obtenus avec un séparateur à haute efficacité, dans un montage conventionnel de broyage à sec, en utilisant de la calcite comme matériau d'essai. Les objectifs du programme ont été les suivants:

- o etablir des données de base sur un broyeur à boulets fonctionnant en circuit fermé avec un séparateur conventionnel, permettant d'obtenir un produit unique;

- o obtenir des données sur un broyeur à boulets fonctionnant en circuit fermé avec un séparateur à haute efficacité, permettant d'obtenir un produit unique:

- o obtenir des données sur un broyeur à boulets fonctionnant en circuit fermé avec classement à deux étages. Le séparateur conventionnel est utilisé pour le classement primaire, et le séparateur à rendement élevé est utilisé pour le classement secondaire du produit fin provenant du séparateur primaire:

- o obtenir des données sur un broyeur à boulets fonctionnant en circuit fermé avec classement à deux étages, permettant d'obtenir un produit unique. Le séparateur conventionnel est utilisé en série avec le séparateur à haute efficacité, ce dernier classifiant le produit refusé au séparateur primaire;

- o obtenir des données sur un broyeur à boulets fonctionnant en circuit fermé avec classement à deux étages permettant d'obtenir deux types de produit. Le séparateur conventionnel est utilisé, comme le séparateur primaire, pour donner un produit ayant une granulométrie à 100% inférieure à 45 micromètres. Le séparateur à rendement élevé, à l'instar du séparateur secondaire, est utilisé pour la fabrication de produits encore plus fins (30, 20, 10 µm).

1.2 Description du programme d'essais

Le programme d'essais concernant le plan d'activités no. 1 comporte cinq essais. Les types de montages utilisés lors de chacun des essais sont les suivants:

Essai no. 1

Le broyeur fonctionne en circuit fermé avec un séparateur à air conventionnel, afin de donner un produit uniforme de granulométrie inférieure à 45 µm, récupéré par un cyclone; l'air provenant du système, passe dans un collecteur de poussières pour récupérer les fines entraînées.

Essai no. 2

Le broyeur fonctionne en circuit fermé avec un séparateur à rendement élevé, afin de donner un produit uniforme de granulométrie inférieure à 45 µm, récupéré par le séparateur à air. Comme dans l'essai no. 1, l'air provenant du système passe par un collecteur de poussières pour récupérer les fines entraînées.

Essai no. 3

Le broyeur fonctionne en circuit fermé avec classement sur deux étages. Le séparateur conventionnel est utilisé comme premier étage et retient les produits grossiers contenant un minimum de particules inférieures à 45 µm. Ce produit subit un nouveau classement dans un séparateur à haute efficacité afin de donner un produit de granulométrie égale à 45 µm. Les produits refusés au niveau des deux séparateurs sont renvoyés directement au broyeur. Comme dans les essais précédents, l'air provenant du système par l'intermédiaire d'un collecteur de poussières, récupère les fines entraînées.

Essai no. 4

Le broyeur fonctionne en circuit fermé avec classement sur deux étages. Le séparateur conventionnel donne un produit inférieur à 45 µm. Les produits refusés au niveau de ce séparateur subissent un nouveau classement à l'aide du séparateur à rendement élevé, dans le but d'enlever les fines inférieures à 45 µm et d'éviter qu'elles ne retournent au broyeur. Comme dans les essais précédents, on utilise l'air provenant du système par l'intermédiaire d'un collecteur de poussières.

Essai no. 5

Le broyeur fonctionne avec classement sur deux étages. Un séparateur à air conventionnel est utilisé pour donner un produit inférieur à 45 µm. Un séparateur à rendement élevé est utilisé pour un nouveau classement des fines, afin de donner un produit encore plus fin inférieur à 30 µm, puis inférieur à 20 µm. De l'air, provenant du système par l'intermédiaire d'un collecteur de poussières, récupère les fines entraînées comme dans les essais précédents.

1.3 Résultats

Se reporter au tableau 1.3-T1 pour les résultats représentatifs des essais effectués au cours du plan d'activités no. 1. On remarque, à partir des résultats expérimentaux de base (Essai no. 1) que la norme du produit, exigeant un passage de 95 à 99% du produit de granulométrie 45µm, a été réalisée à l'aide du séparateur conventionnel.

Tableau 1.3-T1

RESULTATS REPRESENTATIFS DE LA PRODUCTION DU PLAN D'ACTIVITES NO. 1

	Essai				
	1	2	3	4	5
Taux de production:					
- Alimentation nouvelle totale (kg/h)	215	392	387	417	160
- Produit inférieur à 45 µm (kg/h)	213	371	376	409	155
Pourcentage du produit passant de granulométrie 45 µm	99.1	94.6	97.2	98.1	-
20 µm					96.8
Consommation de puissance unitaire					
- Totale (kw-h/tonne)	95.9	70.0	72.5	62.9	178.1
- Inférieure à 45 µm (kw-h/tonne)	96.9	74.1	74.2	70.2	-
- Inférieure à 20 µm					184.4
Charge circulante					
- Séparateur (%)	211	-	211	-	-
- Séparateur à rendement élevé (%)	-	162.4	81	-	-
- Totale (%)	-	-	292	-	-
Rendement à 45 µm (20 µm pour l'essai no. 5)					
- Séparateur (%)	64.5	-	76.7	71.3	87.6*
- Séparateur à rendement élevé (%)	-	82.6	89.3	87.6	52.4
- Ensemble (%)	64.5	82.6	70.2	96.3	44.4

Remarque: Les valeurs données pour la consommation de puissance prennent en compte le broyeur et l'équipement auxiliaire.

* produit de 20 µm.

1016A

En remplaçant le séparateur conventionnel par un séparateur à haute efficacité (soit en comparant les essais no. 1 et no. 2), on a noté les améliorations suivantes:

- o Economie d'énergie moyenne lors de la pulvérisation: 25%
- o Augmentation de l'efficacité du classement: 32%
- o Augmentation du taux de production: 74%

Lors de l'utilisation d'un séparateur à haute efficacité pour effectuer un nouveau classement des produits provenant d'un séparateur conventionnel (comparaison des essais no. 1 et no. 3), on a remarqué les améliorations suivantes:

- o Economie d'énergie moyenne lors de la pulvérisation: 25%
- o Augmentation du rendement du "gyrotor": 18%
- o Augmentation de l'efficacité du classement: 7%
- o Augmentation du taux de production: 82%

Lors de l'utilisation d'un séparateur à haute efficacité pour effectuer un nouveau classement des produits refusés au niveau du séparateur conventionnel (comparaison des essais no. 1 et no. 4), on a remarqué les améliorations suivantes:

- o Economie d'énergie moyenne lors de la pulvérisation: 27%
- o Augmentation du rendement du "gyrotor": 10%
- o Augmentation de l'efficacité du classement: 48%
- o Augmentation du taux de production: 92%

La production conjointe d'un produit inférieur à 45 m et d'un autre ultra-fin (20 µm), à l'aide d'un séparateur à rendement élevé, comme lors de l'essai no. 5, risque d'augmenter de 75% la consommation d'énergie et de 89% le rendement du "gyrotor". Elle risque également de diminuer de 38% à la fois, l'efficacité du classement et le taux de reduction par rapport aux données de base.

Les essais de brillance à sec, comparant la calcite broyée dans un appareil en acier "Ni-hard" à la calcite broyée dans un appareil en céramique, ont montré une légère baisse de brillance (de 0,1 à 0,4%), dans le cas de du produit broyé dans un appareil en acier. Toutefois, les essais de brillance sortant du cadre de la présente étude, n'ont pas été poursuivis dans ce sens le programme d'essais.

1.4 Conclusions

Il résulte des essais conduits dans le cadre du plan d'activités no. 1 qu'un séparateur à rendement élevé, utilisé seul ou conjointement avec un séparateur courant, devrait demander une puissance unitaire moindre, augmenter la production tout en réduisant les frais d'exploitation et ne devrait pas nécessiter d'opérateurs supplémentaires ni de personnel technique de soutien.

2.0 INTRODUCTION

The Canadian Industry Program for Energy Conservation (CIPEC) reported a 15% reduction in energy consumption per tonne of output in 1982, compared to the base year 1974. Much of this saving could be attributed to improved housekeeping. Achieving further conservation would require process modification and fuel switching; both require Research and Development (R&D). The areas for work were grouped as follows:

General R&D -applicable to industrial mineral processing in general

Cement R&D -processing of Portland and other hydraulic cements and gypsum plaster,

Clay products R&D -applicable to manufacture of brick, tile pipe, etc.

The Department of Energy, Mines and Resources (EMR) CANMET, wishing to assist the industrial minerals processing sector in improving the energy efficiency of its operations, commissioned this study.

The overall objective as stated by EMR was,

> To develop the necessary technology to optimize the comminution of industrial minerals in terms of direct and indirect energy consumption.

EMR defined direct and indirect energy consumption in the following way.

> Direct energy consumption measures the work done during the crushing and grinding operations and is expressed in kWh/tonne.
>
> The indirect energy consumption is less frequently recognized and harder to quantify. Its effects are felt during secondary processing or utilization of comminuted materials. The correct size distribution of cement for example could command savings of up to 10% of the amount of cement necessary to make concrete. Optimization of comminution both in terms of kWh/tonne and in terms of processing energy consumption would make a major contribution to energy conservation in the industrial minerals processing sector.

Ten industrial minerals were chosen for study and, to achieve the objective, the work was divided by EMR into three phases.

Phase 1 Plant Studies to Develop a Data Base.

> For each mineral, studies were made of power consumption during comminution at a plant whose operations are typical of the industry. The results are from a brief investigation of the company's operations and therefore, are descriptive rather than analytical.

Phase II Establishment of Monitoring Methodology

> An evaluation was made of commercially available particle size measuring equipment with a view to establishing the feasibility of mill circuit control by on-line particle size measurements.

1016A

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Also under this phase, a proposal for a pilot plant test program was developed.

Phase III Pilot Plant Studies of Comminution Related to Industrial Minerals and Energy Consumption.

This report is presented in accordance with Phase III, Activity I of the study on "Energy Conservation in the Industrial Mineral Sector - Comminution" for Canada Centre for Mineral and Energy Technology (CANMET), Energy, Mines and Resources Canada (EMR).

Witteck Development Inc. of Mississauga, Ontario, and I.M.D. Laboratories Ltd. of Toronto, are responsible for Activities 1, 2, 3, 4, 6 and 7 of the Phase III programme. The activities include the following:

Activity 1 Examination of the performance of a "state of the art" high efficiency classifier in a conventional milling circuit.

Activity 2 Examination, study and analysis of the state of development of classifiers for cement grinding circuits.

Activity 3 Examination of the use of grinding aids and anti-static agents in dry grinding circuits.

Activity 4 Monitoring and control of a dry grinding circuit using a particle size analyzer and programmable controllers.

Activity 6 Evaluation of the use of dry autogenous grinding of silica to produce coarse size sand grade product.

Activity 7 Development of the necessary technology to optimize the comminution of mica.

This report presents the results of the pilot plant testing of the performance of a high efficiency classifier in a conventional dry milling circuit for Activity I at several levels of detail.

- A summary which contains the general description of the test programme, the general results and conclusions. The objectve of this part of the report is to give a general understanding of the test programme and the results without excessive detail.

- Detailed discussion which contains objectives, descriptions, results and conclusions of typical mill and classifier runs for each of the five mill/classifier configurations.

- Working papers which are available for consultation. These papers contain complete results of laboratory and pilot plant tests including lab books, sedigraphs, recording charts, calculations and notes.

3.0 OBJECTIVES

This report examines the performance of a "State of the Art" high efficiency classifier in a conventional dry milling circuit.

The objectives include:

1. Obtain baseline data for a ball mill operated in closed circuit with a conventional classifier to produce a single product.

2. Obtain data for a ball mill operated in closed circuit with a high efficiency classifier to produce a single product.

3. Obtain data for a ball mill operated in closed circuit with two stage classification to produce a single product classification using the following configuration:
   - Conventional classifier as primary classifier
   - High efficiency classifier as secondary classifier handling primary product.

4. Obtain data for a ball mill operated in closed circuit with two stage classification to produce a single product:
   - Conventional classifier as primary classifier
   - High efficiency classifier as secondary classifier handling primary rejects.

5. Obtain data for a ball mill operated in closed circuit with two stage classification to produce two products:
   - Conventional classifier as primary classifier to produce 100% minus 45 micron product.
   - High efficiency classifier as secondary classifier to produce finer product (i.e. 30, 20, 10 microns).

4.0 METHODOLOGY

4.1 General Discussion

The pilot scale test program was operated to examine the performance of a "state of the art" high-efficiency classifier when producing a minus 45 micron product. The program examined the following parameters which had a direct influence on product size, energy utilization, milling efficiency and classifier efficiency:

- Milling circuit configuration
- Classifier selection, operation and control
- Feed material
- Size distribution of feed material
- Size distribution of product
- Circuit feed rate
- Moisture in feed and air
- System air flow and static air pressures
- Atmospheric conditions

4.2 Description of Equipment

4.2.1 Conical Mill

The mill utilized for the pilot plant program was a 1220 mm diameter by 406 mm long Hardinge conical mill. The mill was not operated with discharge grating. The liners were manufactured from Ni-hard steel. The discharge tube to the aspirator was 230 mm in diameter by 406 mm long. The mill bearings were babbitt type and are lubricated with block grease. The mill operated at 31 RPM or 81 percent of critical speed.

The mill was driven by a 25 horsepower electric motor (1770 rpm, 575 volts, 3 phase, 60 cycle) direct coupled to a Winsmith Size 11 differential speed reducer (reduction ratio = 11.9 to 1.0). The gear reducer was direct coupled to the mill pinion gear. The mill drive and power train had an overall mechanical efficiency of 81 percent.

4.2.2 Gyrotor Classifier

The conventional air classfier utilized for the pilot plant program was a 915 mm diameter Hardinge Gyrotor classifier. The classifier was complete with twelve rotor blades on even 30 degree centers constructed from 6.35 mm thick carbon steel plate. The rotor speed was manually controlled by a gear reducer from 30 to 350 RPM. The maximum rotor speed was 350 RPM. The average pressure differential across the classifier was 12.7 mm (water column) at 38°C. The maximum design air flow for the classfier was 1.51 actual cubic meters per second (ACMS) at 38°C.

4.2.3 Cyclone Separator

A 1524 mm diameter cyclone was utilized to remove fines from the air stream during the test programme. The capacity of the cyclone was 1.55 ACMS 38°C. A flop gate at the bottom of the cyclone allowed removal of fines by gravity while maintaining a seal.

4.2.4 Amvest MS-5 High Efficiency Classifier

The high efficiency classifier utilized for the pilot plant was an Amvest Model MS-5 high efficiency classifier. The rented classifier system was a self-contained unit, complete with feed hopper, rotary air locks, system fan, collection cyclone, and control panel. The classifier is illustrated in Figure 4.2.4-F1.

4.2.5 Main Exhaust Fan

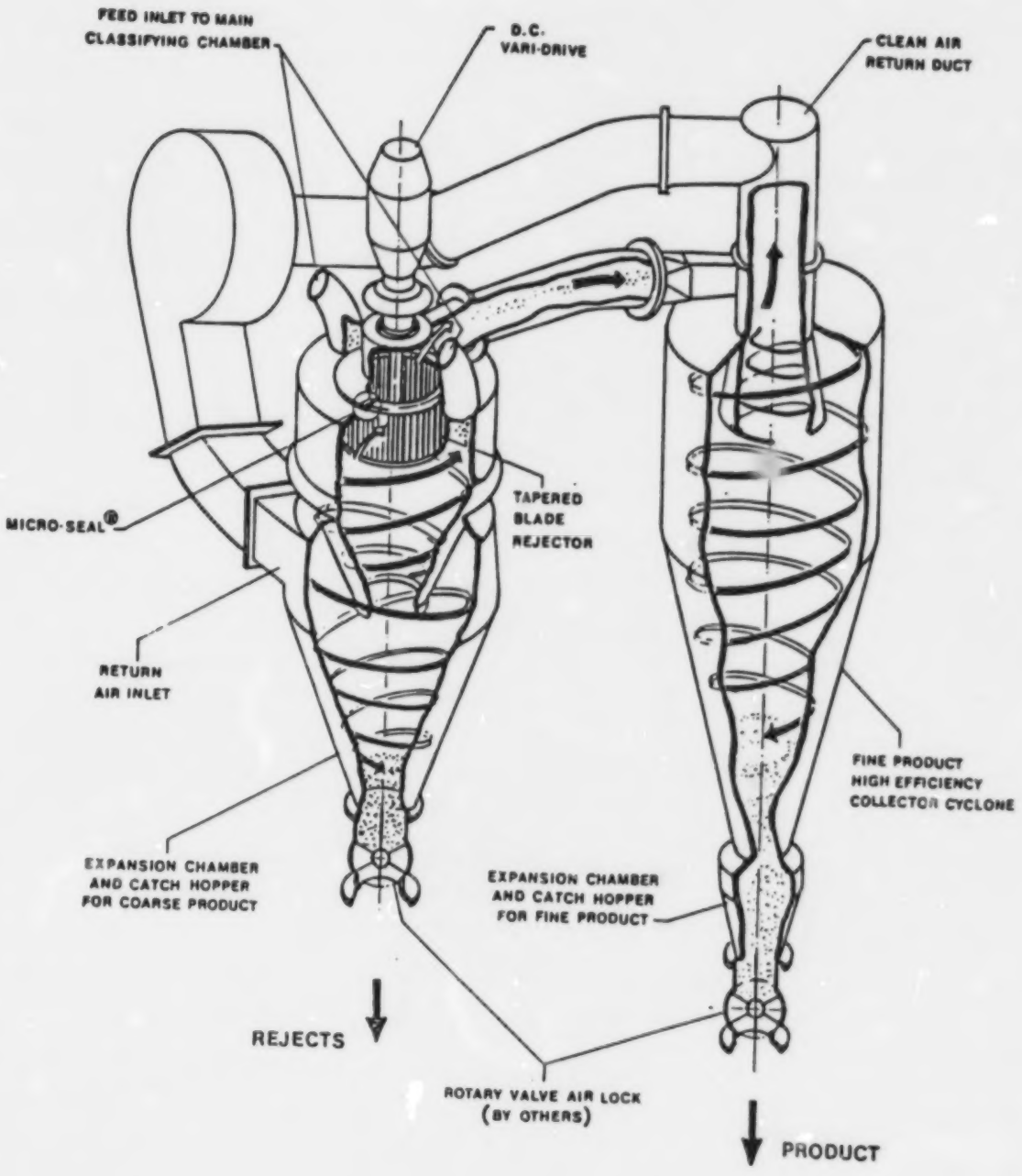
The main exhaust fan utilized for Activity I was a Buffalo Forge, Size 25 MW centrifugal fan with straight paddle blades. The wheel diameter was 445 mm. The outlet area was .052 square metres and the inlet area .057 square metres. The fan was equipped with an extra heavy duty shaft and roller bearings for high speed operation. Fan capacity was 1.6 ACMS at 432 mm W.G. and 20°C.

4.2.6 Dust Collector

The dust collector utilized for Activity I was a Wheelabrator Model MPF-Pulse Dust Collector, size No. 33 with nine filter elements. The filter elements were 330 mm in diameter by 660 mm long, multi-pleated, polyester type filters of 16 oz/sq. yard material. The unit was constructed of 12 gauge M.R.S. welded panels reinformced to withstand 380 mm W.G. pressure. The rated capacity of the dust collector was 2.1 ACMS at 20°C. The elements were cleaned by a pulse of compressed air through the filters. The filters were cleaned on a row by row basis, three at a time, allowing continuous operation of the dust collector.

Figure 4.2.4-F1

AMVEST-MS 5 CLASSIFIER INSIDE THE MICRO-SIZER


FEED INLET TO MAIN CLASSIFYING CHAMBER
D.C. VARI-DRIVE
CLEAN AIR RETURN DUCT
MICRO-SEAL®
TAPERED BLADE REJECTOR
RETURN AIR INLET
FINE PRODUCT HIGH EFFICIENCY COLLECTOR CYCLONE
EXPANSION CHAMBER AND CATCH HOPPER FOR COARSE PRODUCT
EXPANSION CHAMBER AND CATCH HOPPER FOR FINE PRODUCT
REJECTS
ROTARY VALVE AIR LOCK (BY OTHERS)
PRODUCT

4.2.7 Power Measurement

The gross power for the circuit was monitored using a General Electric Type V-625 two element power meter. The power meter was calibrated by Ontario Hydro to ensure the rated accuracy of 1.5%. Individual, panel mounted, ammeters were used to monitor the current requirements for the mill, exhaust fan, and MS-5 classifier. Current requirements for smaller motors, such as the gyrotor, and high efficiency classifier rotor motor, were measured using a hand held induction ammeter.

4.2.8 Particle Size Analyzer

The Particle Size Analyzer used for Activity 1, was a Micrometrics Sedigraph Model 5000 E.T. This analyzer can measure particle sizes from 0.1 to 100 microns with an accuracy of 1%, provided liquid and solid densities are known, and are at a proper temperature. Reproducibility is 1% for particles greater than 1 micron, 3% for particles between 0.5 to 1 micron and 5% for particles below 0.5 micron. Sedigraph results can be displayed as cumulative per cent retained, or cumulative percent passed.

4.3 Test Parameters and Procedures

4.3.1 Classifier Selection and Adjustment

The MS-5 high efficiency classifier was chosen for use in Activity 1, due to its being a complete, self-contained unit with its own collection cyclone, fan and airlocks on the feed product and reject ports, allowing it to be operated independently of the grinding circuit. The cut size of the classifier is adjustable with separation as close as 5 microns.

Characteristics of the classifier were determined in brief shakedown tests. The tests indicated the following:

- Classifier separation efficiency increased with increased auxiliary fan speed.

- Size of separation decreased with increased rotor speed.

- Products in the range of 95-99% minus 45 microns were produced with rotor speeds in the range of 500-1000 rpm and fan speeds over 4000 rpm.

4.3.2 Circuit Feed Material

The test material chosen for Activity 1 was Steep Rock Calcite, Snowhite 6-12. This material did not pose any significant health hazards, did not require any special handling procedures and showed reproducable grinding and classification characteristics. Typical specifications are shown in the following Table 4.3.2-T1.

Table 4.3.2-T1

STEEP ROCK CALCITE

(Calcium Carbonate)

Snowhite 6-12

Chemical Composition (Typical)

$CaCO_3$	94 %
$MgCO_3$	1.8%
Fe_2O_3	0.1%
Alumina (Al_2O_3)	0.1%
Silica	0.8%
Silicates	3 %
Moisture (H_2O)	0.1%

Screen Analysis (Typical)

Mesh	Cum. % Retained
+6	1.5
-6 +16	75
-16 +30	97
-30	100

Physical Properties

Hardness	(MOH's Scale)	3
Specific Gravity		2.71
Bulk Density,	(g/litre)	1470
	(lb/ft^3)	92

1016A

WD1

4.3.3 Product Size

Product specifications for all tests, except Test 5, were given as 95-99% passing 45 microns with minimal minus 10 micron fines. This specification was chosen as typical for the industrial minerals industry.

4.3.4 Classifier Feed Size and Feed Rate

Feed rates to the classifiers were increased until maximum capacity to the classifiers were obtained. Classification efficiency, and recirculating load were monitored to determine the maximum capacity of the classifiers.

4.3.5 Airflow and Static Pressures

Airflow in the system was controlled with two dampers. The fan damper controlled the upflow air from the aspirator to the conventional classifier, and the bleed-air damper controlled the amount of air being swept through the mill. Air flow measurements were taken using a 20 point-traverse with a Pitot tube at the uptake duct. Static pressures were measured using oil-filled manometers, placed at the following locations:

1. fan inlet and outlet
2. mill aspirator
3. conventional classifier inlet and outlet
4. cyclone collector

Typical static differential pressure across the equipment is given in the Table 4.3.5-T1.

Table 4.3.5-T1

Typical Pressure Differential (mm W.G.)

Fan	400-460 mm W.G.
Aspirator	35-65 mm W.G.
Classifier	25-50 mm W.G.
Cyclone	50-75 mm W.G.

Typical Static Pressures (to atmosphere)

Fan Intake	-150	mm W.G.
Fan Outlet	+300	mm W.G.
Uptake	- 60	mm W.G.
Cyclone Inlet	- 50	mm W.G.
Cyclone Outlet	-100	mm W.G.
Dust Collector	+150	mm W.G.

4.3.6 Sample Receiving

The calcium carbonate was received in three shipments of approximately 36 tonnes each, and deposited outside the Witteck pilot plant. The calcite was immediately moved indoors into storage bays to prevent any moisture build up in the material.

4.3.7 Head Sampling

A composite head sample was made from several grab samples taken from each of the indoor storage bays. Since the calcite was of uniform size, it is believed that the head sample size analysis was representative.

4.3.8 Mill Circuit Sampling

The sampling program, set up for Activity 1 consisted of grab samples taken at the following locations:

1) Conventional classifier product, collected from the cyclone collector discharge once every 15 to 20 minutes.

2) Conventional classifier oversize, collected at mill feed spout every 15 to 20 minutes.

3) High efficiency classifier oversize and undersize collected from the rotor air locks discharge every 20 minutes.

4) High efficiency classifier undersize collected from the rotary airlock discharge every 20 minutes.

4.3.9 Screen Analyses and Particle Size Analyses

Screen analyses on all fractions were completed by conventional metallurgical procedures. Minus 200 mesh material was further analyzed with a Micromeritics Sedigraph Particle Size Analyzer.

4.3.10 Clean Up and Disposal

The calcite product was collected in 205 litre drums, and transferred by a Bobcat front end loader to a 10.7 cubic meter bin. A plastic liner in the bin was used to prevent dusting during transport and disposal at a local landfill site.

4.3.11 Tromp Curves

Tromp curves are a statistical method of measuring classifier efficiency. It is a plot of fractional recovery versus particle size, for a given classifier. Fractional recovery refers to the percentage of the feed material at a given particle size, that is recovered in the product. Fractional recovery can also be defined in terms of the material obtained in the tails. In this case fractional recovery (tails basis) = 100-fractional recovery (product basis).

The steeper the Tromp curve, the more efficient the classifier, alternatively the flatter the curve, the less efficient the classifier.

The difference between the maximum fractional recovery and 100% is referred to as bypass. Bypass is the percentage of acceptable fines in the feed that remains in the coarse product, and is returned to the mill for grinding, i.e. misplaced fines.

The tromp curves, presented in this report are calculated as follows:

Step 1

The percent recovery of twelve size fractions was determined from the feed, oversize and undersize, size distribution and mass balance.

$$R_n = \frac{CF_n - CT_n}{CP_n - CT_n}$$

R_n = Percent recovery at particle size n.

CF_n = Cumulative weight percent passing particle size n in the feed

CT_n = Cumulative weight percent passing particle size n in the oversize

CP_n = Cumulative weight percent passing particle size n in the undersize

Step 2

Calculate average recovery of the classifier

$$R_{ave} = \frac{1}{12} \sum_{n=1}^{12} R_n$$

Step 3

Calculate fractional recovery at particle size n

$$R_{frac} = \frac{SP_n}{SF_n} \times R_{ave}$$

SP_n, SF_n = Weight percent between two adjacent particle sizes in the undersize and feed, respectively.

The tromp curve is a plot of R_{frac} versus particle size. This method will product a tromp curve displaying the percent of fines reporting to the undersize. The curves presented in this report are all on this basis.

1016A

4.4 CIRCUIT DESCRIPTIONS AND PROCEDURES

4.4.1 Test 1

The purpose of Test 1 was to examine the performance of a conventional classifier and to obtain base line data for comparison with other classification schemes.

The dry grinding classification circuit was operated as illustrated in Figure 4.4.1-F1. The legend for Figure 4.4.1-F1 is presented in Table 4.4.1-T1.

The grinding mill was operated in closed circuit with a conventional classifier, collection cyclone and fan. Approximately 30 percent of the system air was bled from the system and exhausted through a cartridge dust collector. Makeup air was drawn through the mill. The ground particles from the mill were swept through the aspirator and up the uptake to the air classifier. Coarse particles were removed from the air stream by the classifier and returned directly to the mill via a flop gate and down tube exiting at the mill feed spout. Fine particles were swept into the collection cyclone from which they were removed via a flop gate. Air, with entrained fines, was recirculated to the fan and around the system, except for the bleed stream to the dust collector.

The circuit was operated to produce a final product containing approximately 95 - 99% minus 45 microns.

The objectives of the test were as follows:

- maximize production rate
- minimize unit power consumption, and
- maximize classifier efficiency.

Shakedown tests were performed to establish the mill charge and operating parameters. Initially difficulties were encountered making the required product size. However, this was finally achieved by running the rotor of the classifier close to its maximum speed and decreasing the air flow through the mill aspirator and the air velocity entering the classifier to a condition just above which dropout occurred. Dropout is defined as the condition in the ductwork going from the mill aspirator to the primary classifier inlet when the airflow velocity is insufficient to suspend or transport mill product into the classifier. Dropout causes plugging of ductwork and the mill aspirator.

Test 1 consisted of two mill runs.

During Run 1, the feed rate was set at 227 kg/hr. The classifier was operated with the rotor turning at 285 rpm, corresponding to a rotor tip speed of 13.65 m/sec. Dampers were set to reduce the air velocity to a point just above dropout.

The circuit was operated until conditions reached steady state. This was indicated by a constant production rate and circulating load. Operation of the circuit continued for five hours during which all dependent variables were measured and recorded, samples taken and product collected. A size analysis of the final product was obtained using the Sedigraph 5000 ET and the proportion of minus 325 mesh (45 microns) in the rejects determined by wet screening.

During Run 2, the feed rate was adjusted to 272 kg/hr with other operating parameters the same as Run 1.

Table 4.4.1-T1

LEGEND TEST #1

1. Minus 45 Micron Product

2. Dust Collector Product

3. Gyrotor Fines

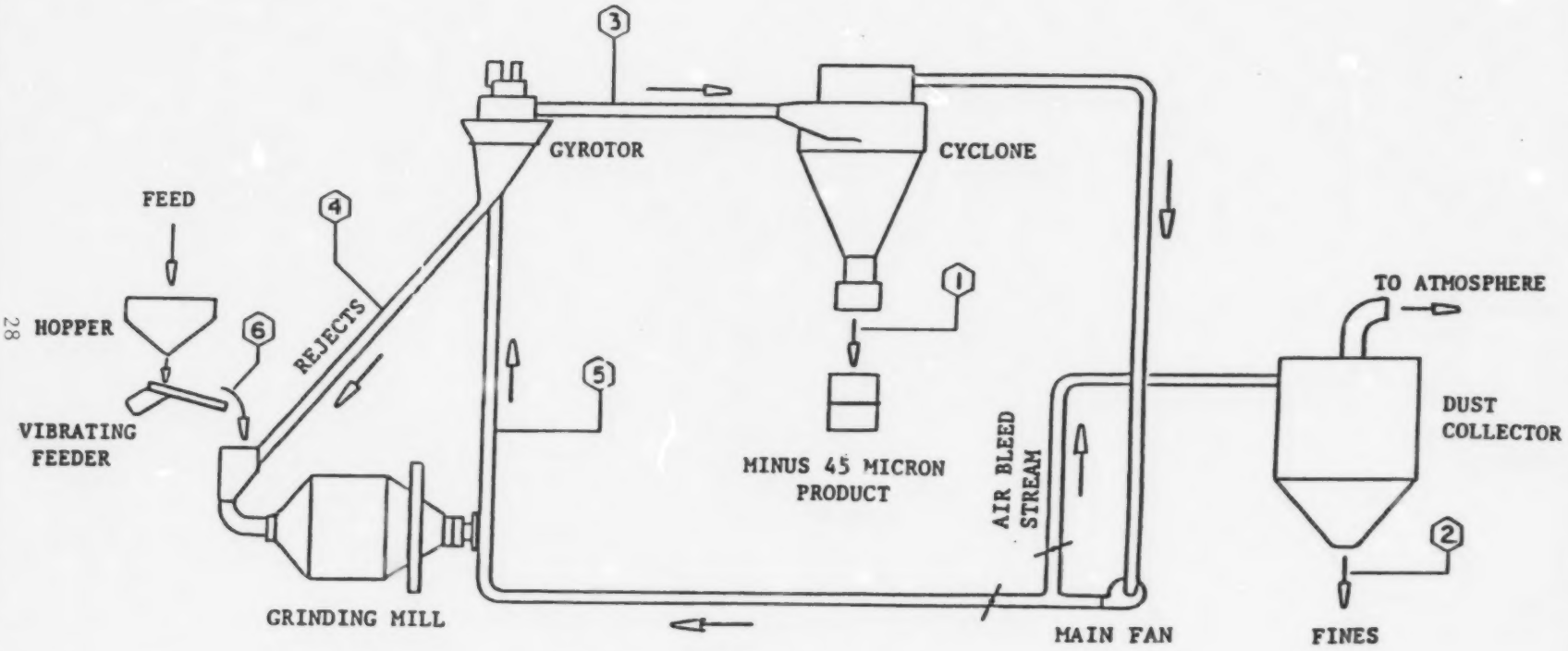
4. Gyrotor Rejects

5. Gyrotor Feed

6. New Feed

1016A

Figure 4.4.1-F1



CIRCUIT CONFIGURATION FOR TEST 1. ACTIVITY 1.

4.4.2 Test 2

The purpose of Test 2 was to examine the performance of a "high-efficiency" air classifier in a dry grinding/classification circuit and to collect data for comparison with the base line case.

The dry grinding/classification circuit was operated as illustrated in Figure 4.4.2-F1. The legend for Figure 4.4.2-F1 is presented in Table 4.4.2-T1.

The grinding mill was operated in closed circuit with the collection cyclone and fan. Approximately 30 percent of the system air was bled from the system and exhaused through a cartridge dust collector. Make-up air was used to sweep ground particles from the mill through the aspirator to the collection cyclone. Material collected by the cyclone fed the high efficiency classifier through a rotary air-lock.

The high efficiency classifier used was totally sealed and equipped with its own collection cyclone, auxilary fan, rotary feed air-lock and rotary product air-lock. Final product was removed from the circuit. The classifier reject material was weighed, mixed with new feed, then added to the mill feed hopper at 6 minute intervals. The mill was fed using a vibrating feeder which was adjusted to maintain a constant feed rate and the level within the feed hopper.

Although the speed of the rotary feed air-lock was adjustable, it was operated at its maximum speed to prevent buildup and possible bridging of material inside the collection cyclone.

The circuit was operated to produce a final product containing approximatley 95-99% minus 45 microns.

The objectives for Test 2 were similar to those for Test 1, i.e.,

- maximize production rate
- maximize unit power consumption, and
- maximize classifier efficiency.

Although mechanical problems were not encountered during shakedown, an extensive series of tests were necessary to establish the performance of the classifier and the classifier/grinding system using the calcium carbonate.

The operating characteristics of the high-efficiency classifier were determined during quick shakedown tests. These are not reported but did indicate the following:

- classifier separation efficiency increased with increased auxilary fan speed.
- size of separation decreased with increased rotor speed
- products in the range of 95-99% minus 45 microns were produced with rotor speeds in the range of 500-1000 rpm and auxilary fan speeds over 3,700 rpm

Test 2 consisted of nine mill runs.

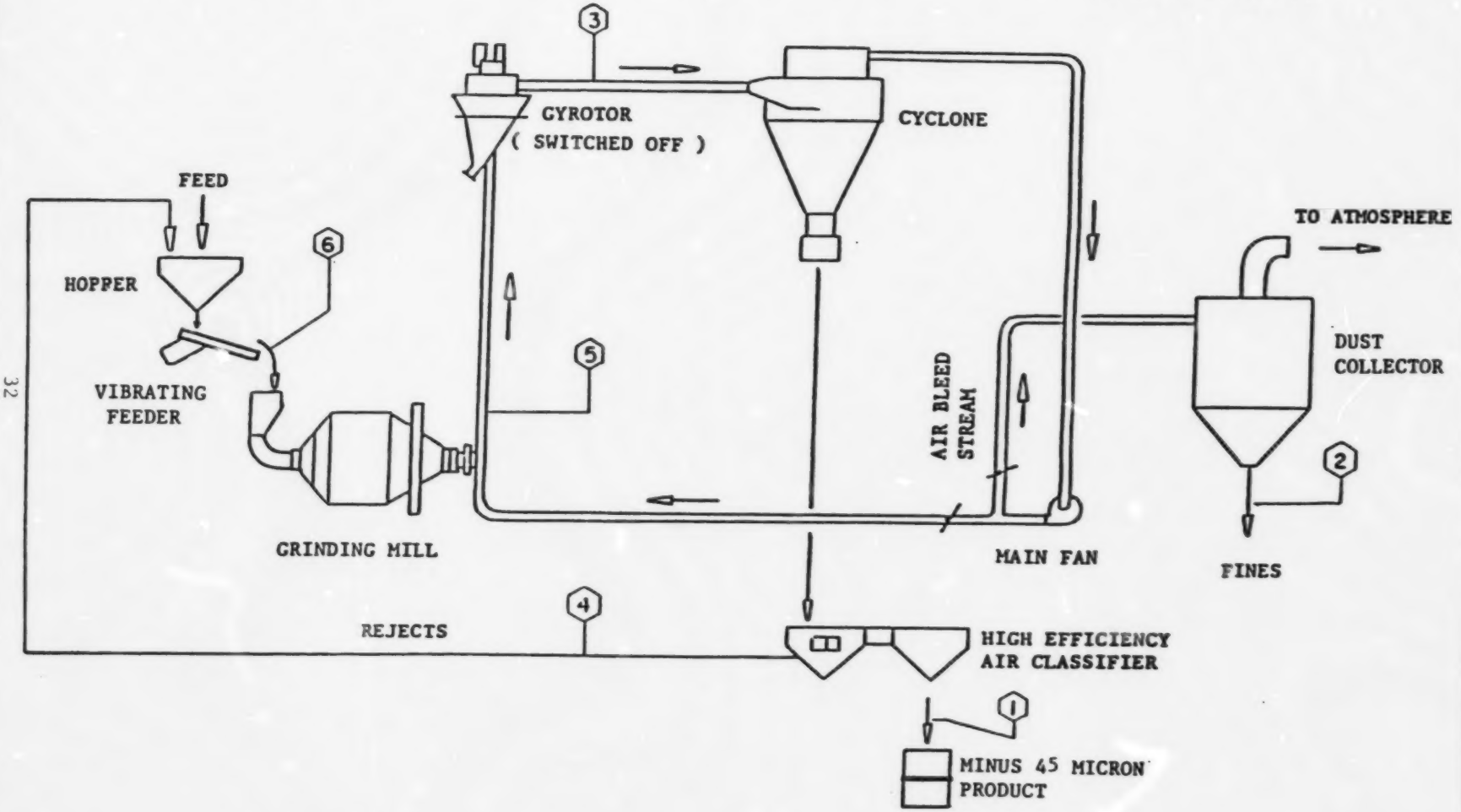
During Run 1, the feed rate was set at 227 kg/hr, the rate at which the conventional classifier was operated most efficiently. The rotor speed was set at 700 rpm and the auxilary fan at 3700 rpm. The dampers were set to slightly increase the air velocity through the grinding mill, aspirator, ducts and cyclone to prevent settling out in horizontal ductwork. The position of all dampers remained unchanged throughout Test 2.

Table 4.4.2-T1

LEGEND TEST #2

1. Minus 45 Micron Product
2. Dust Collector Product
3. Gyrotor Fines
4. Classifier Rejects
5. Gyrotor Feed
6. New Feed

Figure 4.4.2-F1



CIRCUIT CONFIGURATION FOR TEST 2. ACTIVITY 1.

During Run 2 the feed rate was increased to 272 kg/hr. Rotor and auxilary fan speed remained unchanged.

During Run 3 and subsequent tests the auxilary fan speed was increased to 4400 rpm. The classifier rotor speed was adjusted for each test to classify a product containing 95-99% minus 45 microns. The feed rate was gradually increased in order to determine maximum production while maintaining product quality.

4.4.3 Test 3

The purpose of Test 3 was to examine the performance of a grinding/classification circuit consisting of two stages of classification and to collect data for comparison with the base-line and the other circuit configurations.

The dry grinding/classification circuit was operated as illustrated in Figure 4.4.3-F1. The legend for Figure 4.4.3-F1 is presented in Table 4.4.3-T1.

The grinding mill was operated in closed circuit with two-stage classification. This consisted of a conventional classifier for the first stage and a high efficiency classifier for the second. The second stage treated product from the first stage.

The conventional classifier was operated to produce a relatively coarse product to be retreated by the high-efficiency classifier. Rejects from the conventional classifier were returned directly to the mill. Rejects from the high-efficiency classifier were collected over 6 minute periods, weighed, mixed with new feed and added to the mill feed hopper.

The high efficiency classifier was operated to produce a final product of approximately 95-99% minus 45 micron material.

The objectives of Test 3 were as follows:

- minimize return of fines to the grinding mill
- maximize production rate
- minimize unit power consumption, and
- maximize classification efficiency.

Shakedown problems were minimal since both classifiers had been characterized in previous tests. The dampers were set to maintain air velocities at levels preventing material dropout. Once set, these remained unchanged throughout the test.

Test 3 consisted of four runs.

During Run 1 the feed rate was set at 408 kg/hr. The conventional classifier was operated with the rotor turning at 160 rpm with a corresponding tip speed of 7.60 m/sec. The rotor speed of the high efficiency classifier was set at 550 rpm and the auxilary fan speed at 4400 rpm.

Run 1 was operated until steady state conditions were obtained as indicated by constant circulating loads and production rate. Operation was continued for 1 1/2 hours to collect data and samples. Although the run was successful, it was decided to repeat the test using the same conditions. During Run 2 the circulating load of the conventional classifier climbed to a very high level. Overall production remained high, but it was evident that adjustments were required if the circuit was to be pushed for maximum production rate.

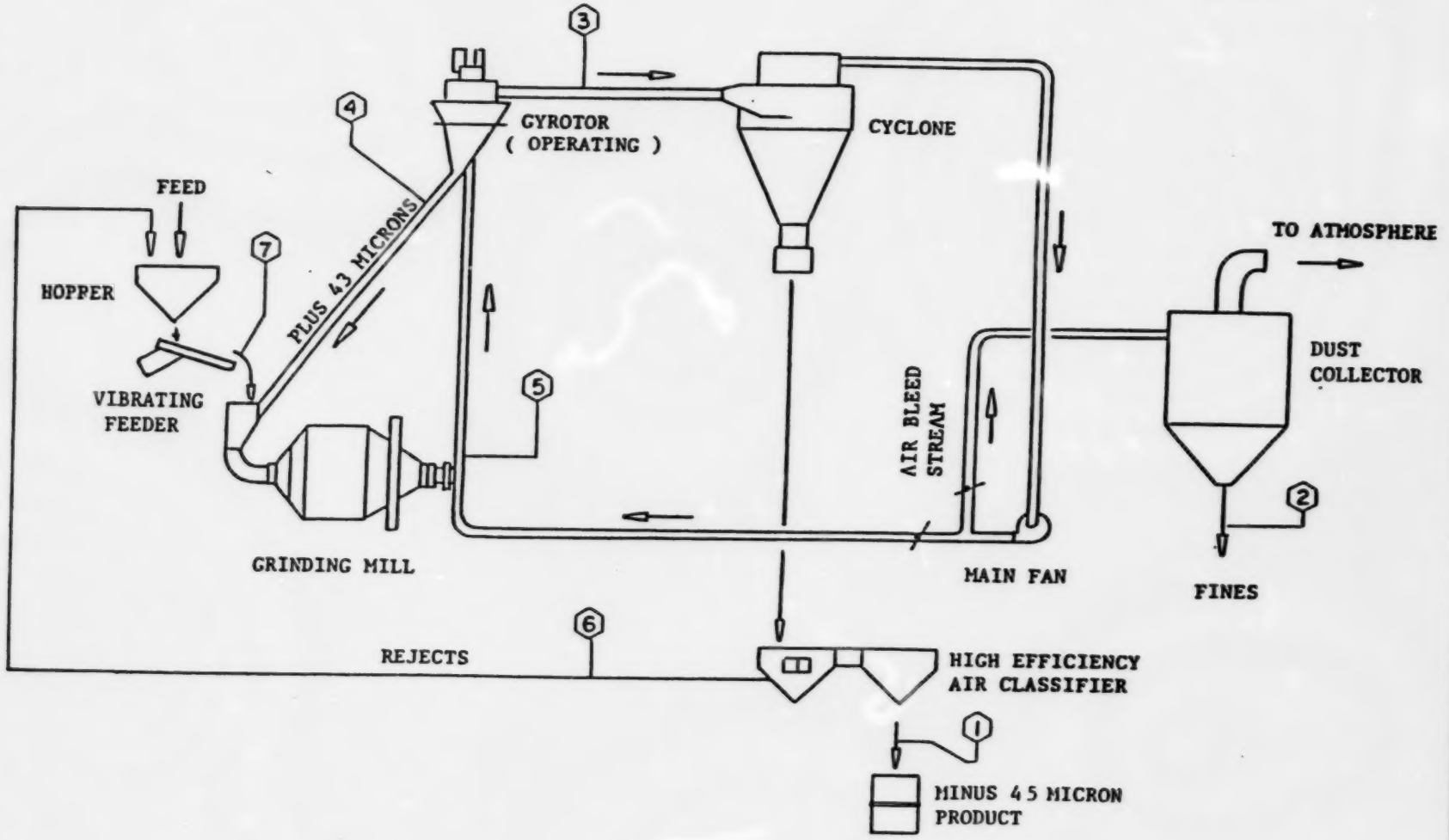
Run 3 was therefore operated with a lower rotor speed for the conventional air-classifier: 150 rpm, corresponding to 7.2 m/sec. tip speed. The feed rate was also reduced to 386 kg/hr.

Table 4.4.3-T1

LEGEND TEST #3

1. Minus 45 Micron Product
2. Dust Collector Product
3. Gyrotor Fines
4. Gyrotor Rejects
5. Gyrotor Feed
6. Classifier Rejects
7. New Feed

Figure 4.4.3-F1



CIRCUIT CONFIGURATION FOR TEST 3. ACTIVITY 1.

The high efficiency classifier operating parameters were the same as for Runs 1 and 2. These operating parameters effectively reduced the quantity of material recirculated back to the mill by the conventional classifier.

The objective of Run 4 was to optimize the circuit for maximum production. To achieve this, the feed rate was increased back to 408 kg/hr and the rotor speed of the high efficiency decreased to 428 rpm to slightly coarser in the final product. Other operating parameters remained identical to Run 3.

4.4.4 Test 4

The purpose of Test 4 was to examine the performance of a grinding/classification circuit using a high efficiency classifier to clean fines from the rejects of a conventional air classifier and to collect data for comparison with the base-line and other cases.

The dry grinding/classification circuit was operated as illustrated in Figure 4.4.4-F1. The legend for Figure 4.4.4-F1 is presented in Table 4.4.4-T1.

The grinding mill was operated in closed circuit with the conventional air classifier, collection cyclone and fan. The circuit was operated in the same manner as Test 1. However, rejects from the conventional classifier were fed to the high-efficiency classifier to remove fine material that had already been ground to final product size, i.e., misplaced fines. Products from both the conventional and high efficiency classifiers were removed from the circuit. Rejects (oversize) from the high efficiency classifier were returned to the mill.

The circuit was operated to produce two final products, both containing approximately 95-99% minus 45 micron material.

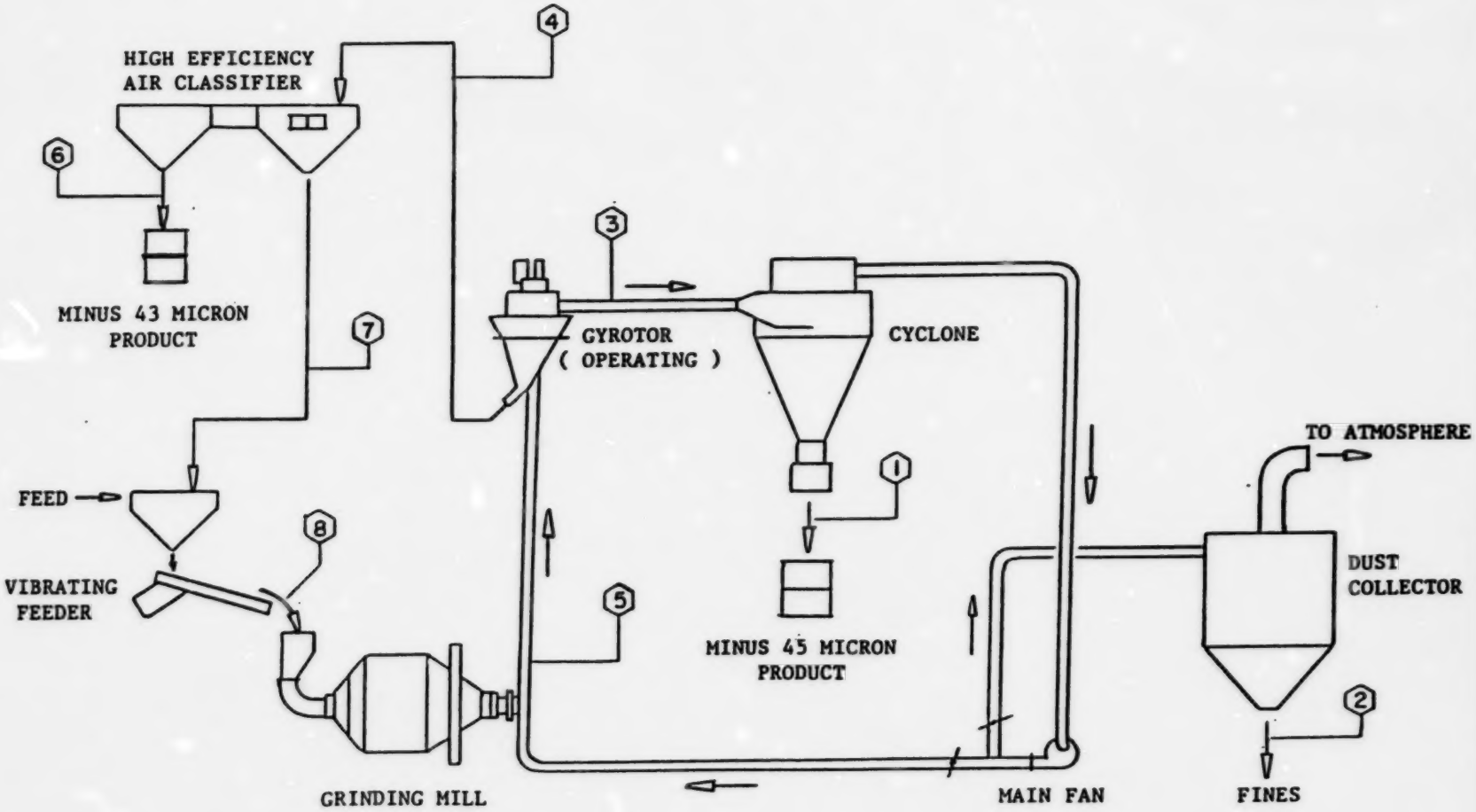
1016A

Table 4.4.4-T1

LEGEND TEST #4

1. Minus 45 Micron Product
2. Dust Collector Product
3. Gyrotor Fines
4. Gyrotor Rejects
5. Gyrotor Feed
6. Minus 45 Micron Product
7. Classifier Rejects
8. New Feed

Figure 4.4.4-F1



CIRCUIT CONFIGURATION FOR TEST 4. ACTIVITY 1.

Test 4 consisted of three runs.

During Run 1, the feed rate was set at 318 kg/hr. The conventional classifier was operated with the rotor turning at 285 r.p.m. with a corresponding tip speed of 13.6 m/sec. Dampers were set to reduce the air velocity to a point just above dropout conditions. The rotor speed of the high efficiency classifier was set at 575 r.p.m. and the auxiliary fan speed at 4,400 r.p.m. Run 1 continued for two hours to collect data and samples after steady state conditions were achieved. The run was successful, resulting in the highest overall classification efficiency (at 45 microns) since the pilot plant tests had begun.

Run #2 was operated at a higher feed rate (454 kg/hr), with all other variables remaining unchanged from Run 1. Results of this run were again successful, with a very high classification efficiency (over 97%).

The production rate for Run 3 was set at 500 kg/hr with all other parameters remaining unchanged from the previous tests. The classifier efficiency decreased somewhat, but was still high at over 90%. Under these conditions, the amount of misplaced material returned to the mill was reduced dramatically.

4.4.5 Test 5

The purpose of Test 5 was to collect data while producing progressively finer products using a grinding/classification circuit with two stages of classification.

The dry grinding/classification circuit was operated as illustrated in Figure 4.4.5-F1. The legend for Figure 4.4.5-F1 is presented in Table 4.4.5-T1.

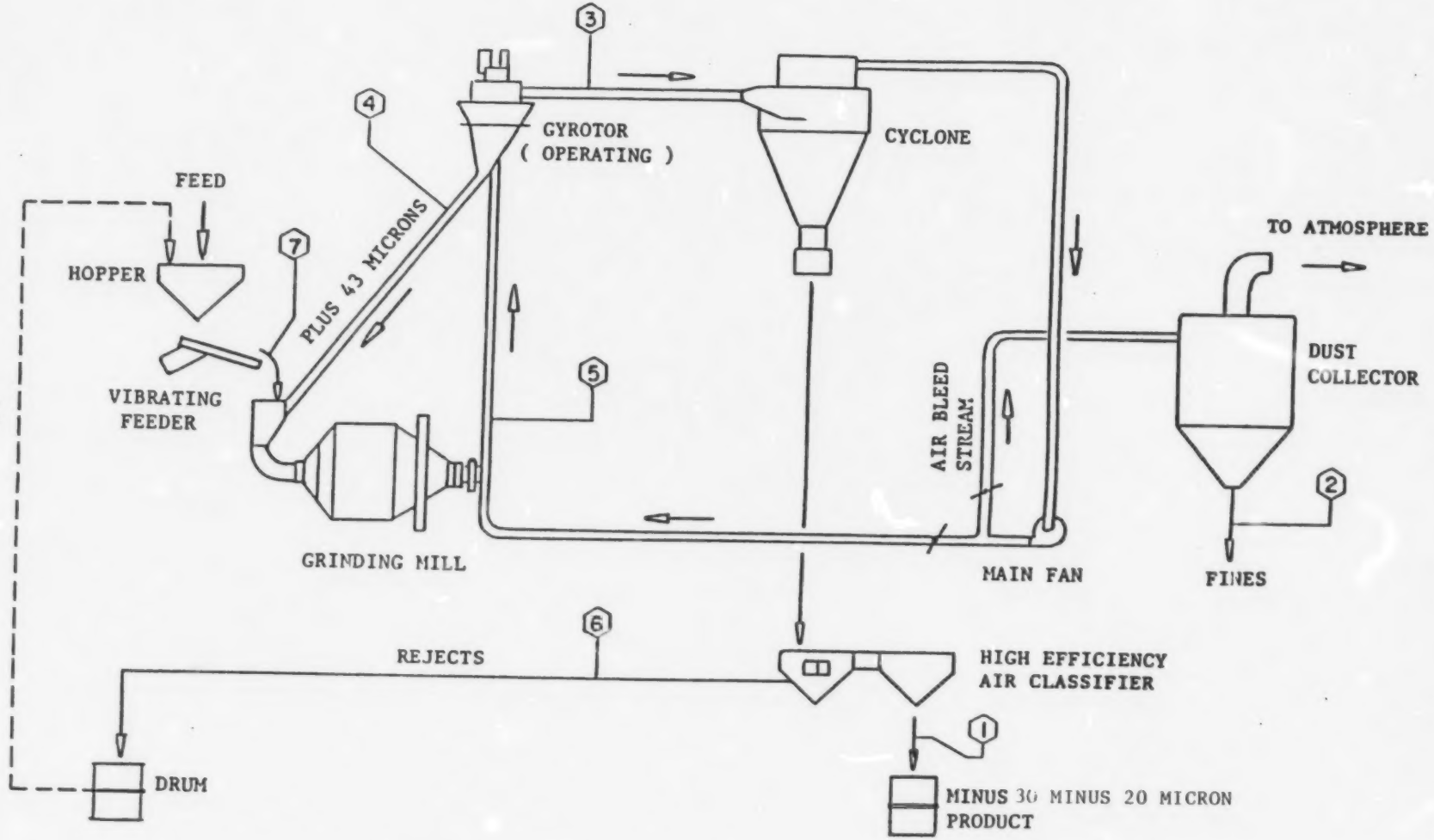
Table 4.4.5-T1

LEGEND TEST #5

1. Minus 45 Micron Product
2. Dust Collector Product
3. Gyrotor Fines
4. Gyrotor Rejects
5. Gyrotor Feed
6. Classifier Rejects
7. New Feed

1016A

Figure 4.4.5-F1



CIRCUIT CONFIGURATION FOR TEST 5. ACTIVITY 1

The grinding mill was operated in closed circuit with two-stage classsification. A conventional classifier was used for the first stage and the high-efficiency classifier for the second. The second stage treated the product from the first stage. Set up and general operation were identical to Test 4, but operating parameters were changed to meet the objectives of the individual test runs.

Test 5 consisted of 6 runs.

The circuit was operated during Run 1 to produce a product from the conventional classifier containing approximately 95-99% minus 45 microns. That product was treated by the high-efficiency classifier to produce two products: a "coarse" and a "fine". The speed of the rotor was varied to change the cut size of the unit, and thereby adjust the size range of the products produced.

The feed rate was set at 227 kg/hr. The conventional classifier was operated with its rotor turning at 335 r.p.m., corresponding to a rotor tip speed of 16 m/sec. Dampers were set to reduce the air velocity to a point just above dropout.

Initially, the rotor of the high-efficiency classfier was switched off, but the fan and air-locks switches were on. All of the product reported to the "fines" side (i.e. to the self-contained cyclone). This enabled verification that the conventional air classifier product size was approximately 95-99% minus 45 microns. The circuit was operated in this fashion until conditions reached steady state. This was indicated by a constant production rate and circulating load.

The rotor of the high efficiency classifier was switched on after steady state was achieved and a series of tests were run at progressively faster rotor speeds. These tests were run for approximately fifteen to twenty minutes each. This was sufficient time to record data and collect samples because the classifier response to changed operating conditions was instantaneous.

The objective of Run 2 was to produce one product of approximately 95-99% minus 30 micron material.

The conventional classifier was operated to produce a relatively coarse product to be retreated by the high efficiency classifier. Rejects from the conventional classifier were returned directly to the mill. Rejects from the high efficiency classifier were collected over 6 minute periods, weighed, mixed with new feed and added to the mill feed hopper.

The feed rate was set at 227 kg/hr. The conventional classifier was operated with the rotor turning at 170 rpm, with a corresponding tip speed of 8 m/sec. The rotor speed of the high efficiency classifier was set at 1100 rpm and the auxiliary fan at 4400 rpm.

The objective of Run 3 was to produce one product of approximately 95-99% minus 20 micron material.

The feed rate for Run 3 was set at 180 kg/hr. The conventional classifier was operated at 180 rpm, with a corresponding tip speed of 8.6 m/sec. The rotor speed of the high efficiency classifier was set at 1400 rpm and the auxiliary fan at 4400 rpm.

The objective of Run 4 was to produce one product of approximately 95-99% minus 10 micron material.

The feed rate for Run 4 was set at 90 kg./hr. The conventional classifier was operated at 180 rpm, with a corresponding tip speed of 8.6 m/sec. The rotor speed of the high efficiency classifier was set at 1400 rpm and the auxiliary fan at 4400 rpm.

Runs 5 and 6 were operated under the same conditions as Run 4.

5.0 DISCUSSIONS AND RESULTS

5.1 Test 1

Test 1 established base line data using a conventional classifier to produce a final product containing 95-99% minus 45 micron material. The flowsheet is illustrated in Figure 5.1-F1 and operating conditions given in Table 5.1-T1.

Table 5.1-T1

TEST 1 OPERATING CONDITIONS

		Run 1	Run 2
Nominal Feed Rate	(kg/hr)	227	272
Conventional Classifier:			
Rotor speed	(rpm)	285	285
Rotor tip speed	(m/min)	819	819
Air Temperature	(^{o}C)	-	41
Uptake Velocity	(m/min)	655	

During Test 1, the objective of making a product containing 95-99% minus 45 micron material was achieved. As illustrated in Figure 5.1-F2, the product curves are relatively flat, with a high amount of fines, low classifier efficiency and a large proportion of final product (minus 45 microns) was being returned to the mill for regrinding. The Tromp curves, as shown in Figure 5.1-F3 also are relatively flat showing poor classification efficiency.

In Run No. 1 for example, only 25% of the 45 micron material was recovered in the undersize and up to 25% of the minus 10 micron material was returned to the mill for further grinding.

The production rate averaged 215 kg/hr between the two runs, with power consumption averaging 96 kWhr/tonne.

The measured and derived data for Test 1 is presented in Table 5.1-T2.

Test 1 indicated that the grinding/classification circuit using a conventional classifier in closed circuit with the mill had difficulty in producing a 95-99% minus 45 micron product, with a minimum 10 micron fines, at an acceptable energy consumption. More energy is required for milling because of the inefficiency of the conventional classifier and the high percentage of product returned to the mill. The product returned to the mill consumed energy, reduced the production rate, and produced an excessively fine product.

Table 5.1.T2

Test 1

Measured Data

		Run 1	Run 2
Test period	hrs:min	5.48	4:56
Final product			
- total produced	kg	1292	1010
- product size	@ 45 microns	98	99
Dust collector			
- total produced	kg	13	12
- product size	@ 45 microns	100	100
Classifier returns			
- production rate	kg/hr	410	490
- product size	@ 325 mesh	24	28
High efficiency classifier returns			
- production rate	kg/hr	-	-
- product size	@ 325 mesh	-	-
Power consumed	kWh	120.9	101.4

Derived Data

Production Rate			
- total	kg/hr	225	205
- minus 45 micron	kg/hr	223	203
Unit Power Consumption			
- total	kWh/tonne	92.6	99.2
- minus 45 micron	kWh/tonne	93.6	100.1
Circulating Load			
- classifier	%	182	239
- high eff. class.	%	-	-
- total	%	-	-
Efficiency			
- classifier	%	69.3	59.7
- high eff.class.	%	-	-
- overall	%	-	-

1016A

WD1

FIG. 5.1-F1

TEST 1

TYPICAL MATERIAL FLOW IN kg/hr

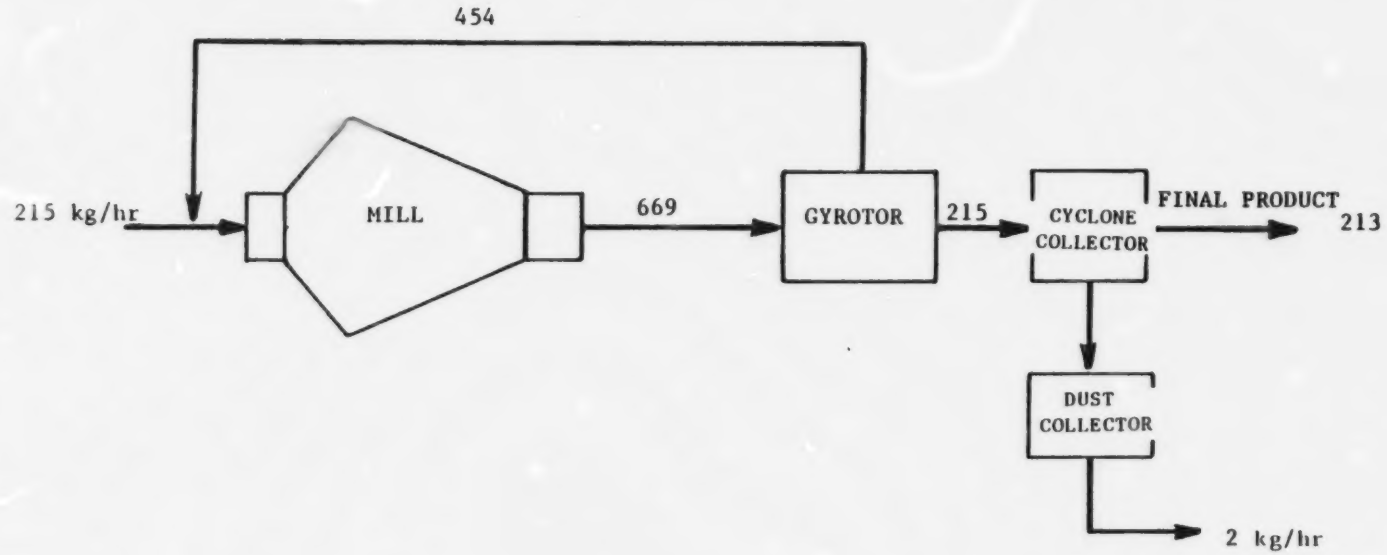
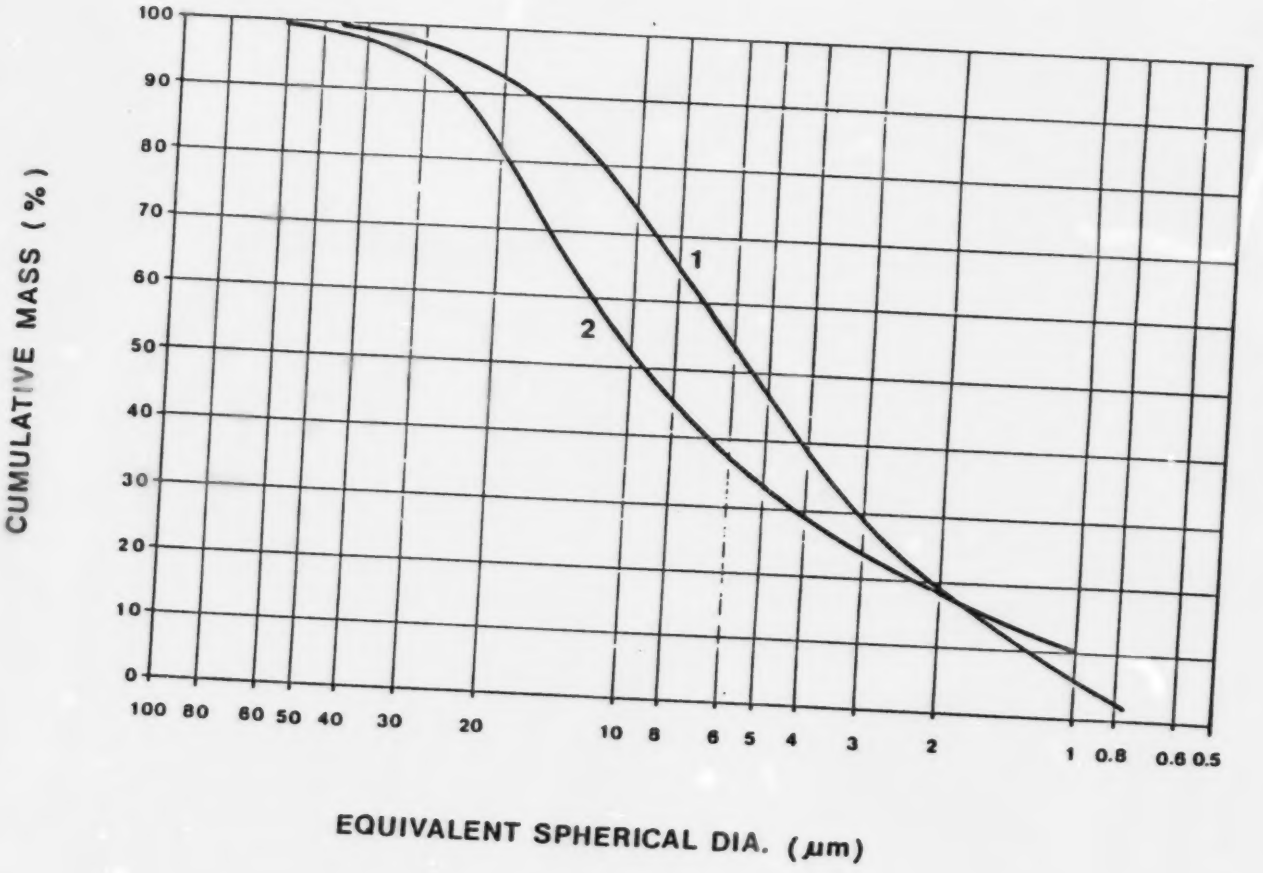


Figure 5.1-F2

PARTICLE SIZE DISTRIBUTION

TEST No.1 RUN No.1&2

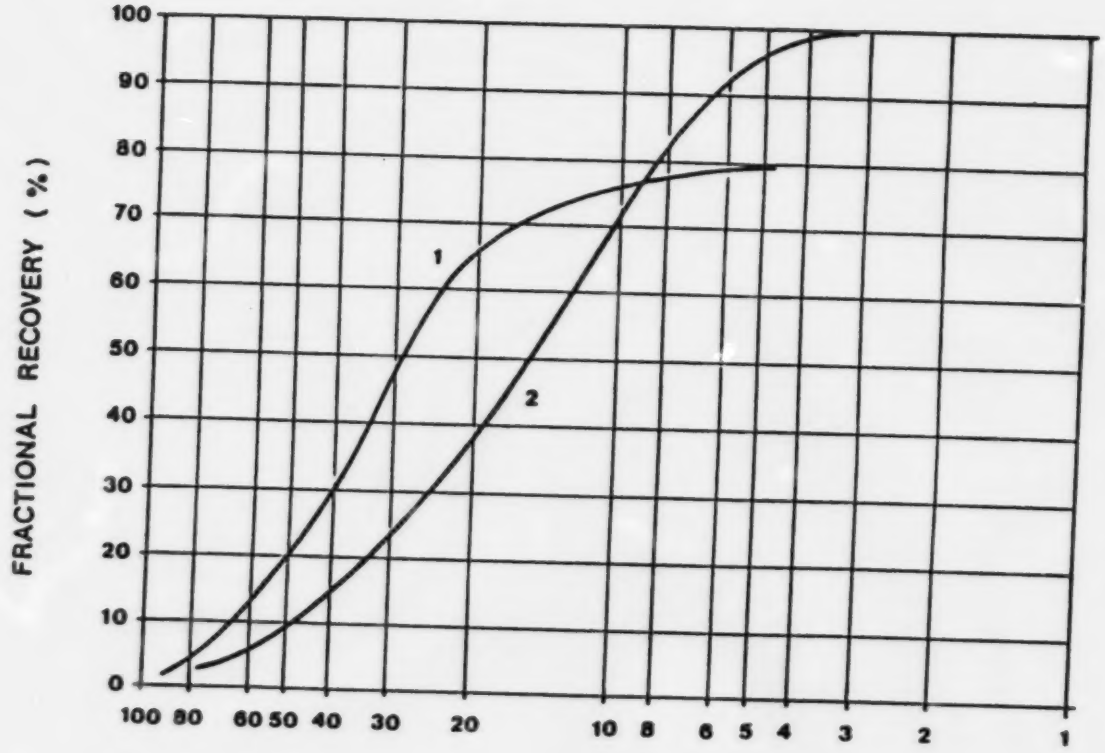


TROMP CURVE

Figure 5.1-F3

TEST No.1 RUN No.1&2

PERCENT REPORTING TO UNDERSIZE



5.2 Test 2

Test 2 provided data to compare the performance of a high efficiency classifier with a conventional classifier in a grinding/classification circuit producing a final product containing approximately 95-99% minus 45 micron material. The flowsheet is illustrated in Figure 5.2-F1. The operating conditions are presented in Table 5.2-T1.

Table 5.2-T1

TEST 2 OPERATING CONDITIONS

		Run				
		1	2	4	5	9
Nominal Feed Rate		227	272	250	227	408
High Efficiency Classifier						
- Rotor speed		700	700	600	720	570
- Fan speed		3700	3700	4400	4400	4400
Air Temperature		37°	37°	37°	37°	37°
Uptake Velocity	m/min	928	928	928	928	928

Table 5.2-T2

Test 2

		Runs				
		1	2	4	5	9
Measured Data						
Test period	hrs:min	1:45	2:00	2:55	2:50	1:24
Final product						
- total produced	kg	361	462	729	514	545
- product size	@ 45 microns	99.5	99.5	96.0	98.0	94.5
Dust collector						
- total produced	kg	4	6	9	16	5
- product size	@ 45 microns	100	100	100	100	100
Classifier returns						
- production rate	kg/hr	-	-	-	-	-
- product size	@ 325 mesh	-	-	-	-	-
High efficiency classifier returns						
- production rate	kg/hr	724	1018	298	250	636
- product size	@ 325 mesh	28.3	38.3	10.5	15.7	13.0
Power consumed	kWh	42.2	47.2	76.3	76.7	38.4
Derived Data						
Production Rate						
- total	kg/hr	208	234	253	187	392
- minus 45 micron	kg/hr	207	233	243	183	371
Unit Power Consumption						
- total	kWh/tonne	115.7	100.9	103.3	144.7	70.0
- minus 45 micron	kWh/tonne	116.3	101.3	107.7	147.6	74.1
Circulating Load						
- classifier	%	-	-	-	-	-
- high eff. class.	%	347.6	434.9	117.6	133.7	162.4
- total	%	-	-	-	-	
Efficiency						
- classifier	%	-	-	-	-	
- high eff.class.	%	50.0	37.5	89.0	82.7	82.6
- overall	%	-	-	-	-	-

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FIG. 5.2-F1

TEST 2

TYPICAL MATERICAL FLOW IN kg/hr

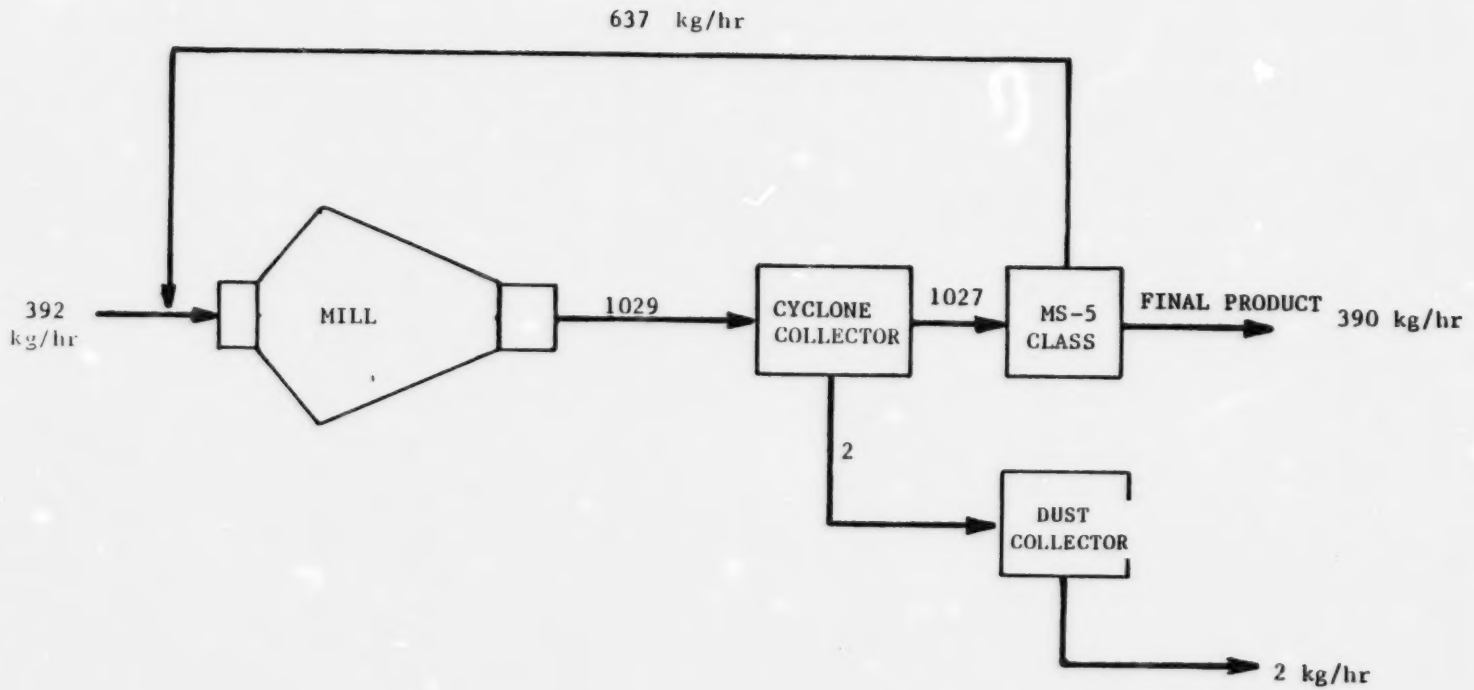


Figure 5.2-F2

PARTICLE SIZE DISTRIBUTION

TEST No.2 RUN No.1,2,4,5&9

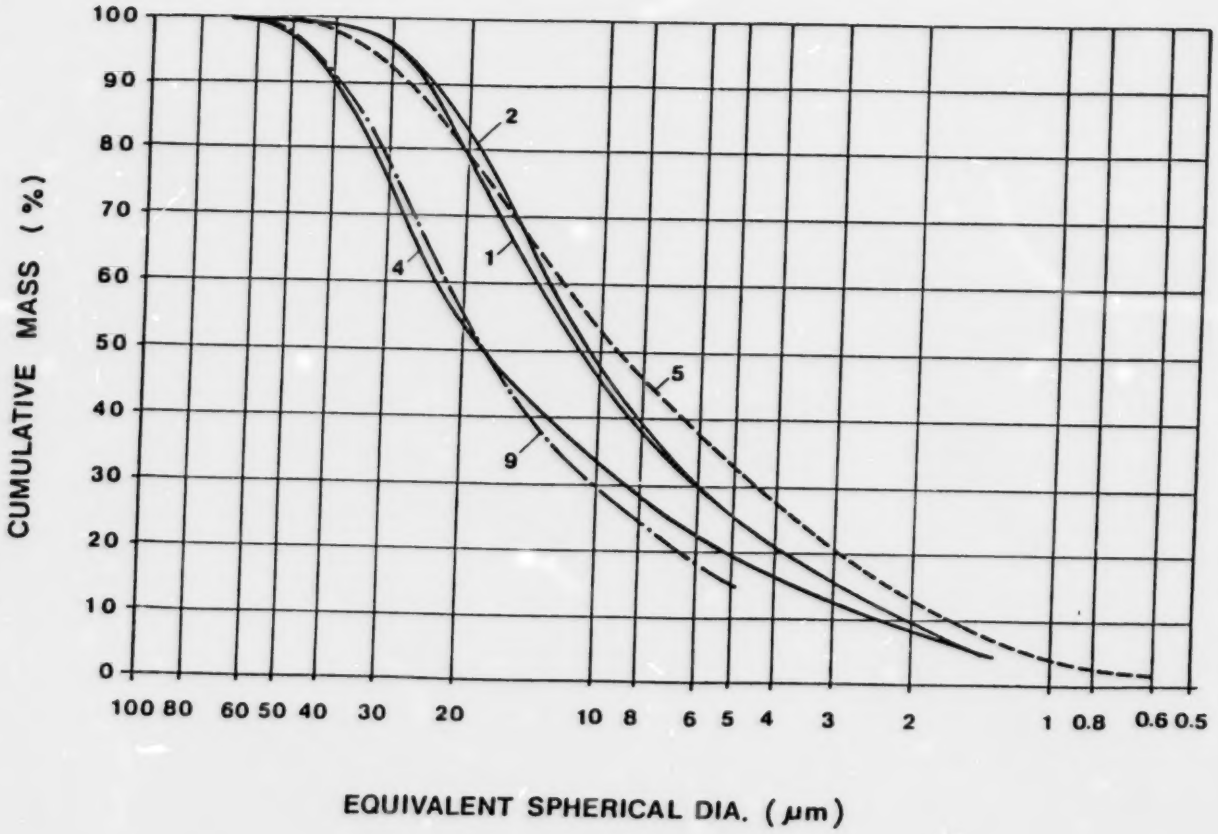
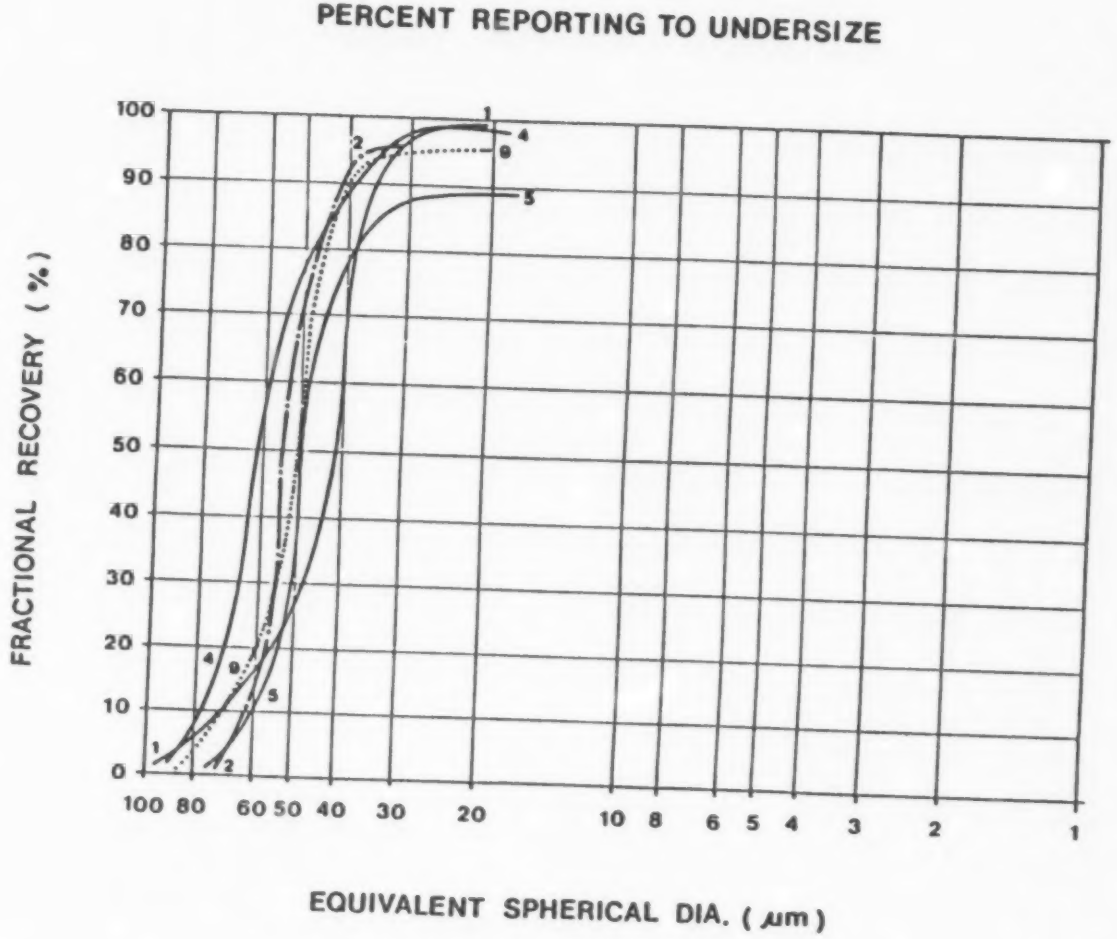


Figure 5.2-F3

TROMP CURVE

TEST No. 2 RUN No.1,2,4,5&9



A product containing 95-99% minus 45 micron material was achieved in all runs of Test 2, except Run 9, when the objective was to maximize production. During Run 9, the fines content decreased slightly below the target level to 94%. The high efficiency classifier had the capability of producing a sufficiently fine product. Attention was focussed on increasing the production rate, minimizing power consumption, increasing classification efficiency and reducing the return of fines to the mill.

The fan and rotary air locks on the high efficiency classifier consumed energy in addition to that consumed by the classifier rotor, main exhaust fan and mill. The rate of energy consumption for the circuit was higher (ave. 25.3 kWhr) for Test 2, than for the Test 1 circuit (avg. 20.5 kWhr). However, since the nominal feed rate was below 318 kg/hr, the unit power consumption (kWhr/tonne) was higher than in Test 1. Since the high efficiency classifier was capable of producing specified product at 393 kg/hr, unit power consumptions decreased over that achieved in Test 1.

The product size distribution curves and Tromp curves (Figures 5.2-F2 and 5.2-F3) are steeper than those of the conventional classifier indicating a substantial increase in classifier efficiency.

By comparing Runs 1 and 2 with 4 and 9 in Table 5.2-T2, with the size distribution curves shown in Figure 5.2-F2, one can see the improvement in product quality (steeper curves) with the decreased circulating load and higher classifier efficiency. The fan speed of the classifier has a considerable effect on efficiency as at Runs 1 and 2, it was set at 3700 rpm and for Runs 4, 5 and 9 it was set at 4400 rpm. High rotor speed (Run 5) produced a large amount of fines, flattening the product curve somewhat, but had little effect on overall classifier efficiency.

Examination of the results for Test 2 indicate that the required product size (95-99% minus 45 microns) was achieved using the high efficiency classifier at production rates far higher than those achieved using the conventional classifier. Unit energy consumption was lower despite an increased number of motors in the circuit. Classification efficiency was increased significantly with the result that the final product contained substantially fewer fines indicating a substantial increase in classifier efficiency.

5.3 Test 3

Test 3 compared the performance of a two-stage classification circuit with a single stage classification circuit using either a conventional or high efficiency air classifier. The flowsheet is illustrated in Figure 5.3-F1 and operating conditions given in the Table 5.3-T1.

Table 5.3-T1

TEST 3 OPERATING PARAMETERS

		Run			
		1	2	3	4
Nominal Feed Rate	(kg/hr)	408	408	363	408
Conventional Classifier					
- rotor speed	(rpm)	160	160	150	150
- rotor tip speed	(m/min)	460	460	430	430
High Efficiency Classifier					
- rotor speed	(rpm)	550	550	500	428
Classifier Fan					
- speed	(rpm)	4400	4400	4400	4400
Air Temperature	(^{o}C)	33	33	33	33
Uptake Velocity	(m/min)	933	933	933	933

The circuit was operated to collect a coarse product in the conventional cyclone. This product was classified by the high efficiency classifier to produce 95-99% minus 45 micron material. This objective was achieved in all runs of Test 3.

During the initial runs, the overall classification efficiency for both classifiers operating in closed circuit with the mill was lower than using the high efficiency classifier alone. This was a consequence of a relatively high re-circulating load. The rotor speed of the conventional classifier was decreased in order to produce a coarser product and drop circulating load. The high-efficiency classifier remained unadjusted.

1016A

Examination of the results for Test 3 indicates that the required product size could be readily achieved using the two stage classification circuit with conventional and high efficiency classifiers. The measured and derived data is presented in Table 5.3-T2. The product particle size distribution is presented in Figure 5.3-F2. The Tromp curves based on the combined efficiency of both classifiers, are presented in Figure 5.3-F3. The production rate was substantially higher than for the conventional classifier alone, and slightly higher than using the high efficiency classifier alone.

The effect of dropping the classifier rotor speed on the circulating load, efficiency of classification and final product size analysis was substantial. The amount of material recirculated by the conventional air classifier decreased from over 400% to 58%. Total recirculating load decreased from 489% to 133% resulting in fewer minus 10 micron fines in the final product, as shown in the size distribution curves.

Classification efficiency was sensitive to the operation of the conventional classifier and the amount of material recirculated.

Table 5.3-T2

Test 3

		Runs			
		1	2	3	4
Measured Data					
Test period	hrs:min	1:28	2:00	1:45	1:57
Final product					
- total produced	kg	548	765	688	841
- product size	@ 45 microns	99	98	96	96
- product size	@ 10 microns	42	49	35	36
Dust collector					
- total produced	kg	4	5	10	10
- product size	@ 45 microns	100	100	100	100
Classifier returns					
- production rate	kg/hr	569	1633	231	762
- product size	@ 325 mesh	17	17	14	23
High efficiency classifier returns					
- production rate	kg/hr	388	250	301	430
- product size	@ 325 mesh	16	16	12	12
Power consumed	kWh	41.0	56.0	49.1	54.8
Derived Data					
Production Rate					
- total	kg/hr	376	385	399	436
- minus 45 micron	kg/hr	373	373	383	419
Unit Power Consumption					
- total	kWh/tonne	74.3	72.8	70.3	64.5
- minus 45 micron	kWh/tonne	75.1	74.2	73.2	67.1
Circulating Load					
- classifier	%	151.1	424.2	58.0	174.7
- high eff. class.	%	103.2	64.9	75.4	98.7
- total	%	254.3	489.1	133.4	273.4
Efficiency					
- classifier	%	79.6	58.1	92.5	71.0
- high eff.class.	%	85.8	90,6	91.7	89.4
- overall	%	70.5	54.8	85.4	65.5

FIG. 5.3-F1

TEST 3

TYPICAL MATERIAL FLOW IN kg/hr

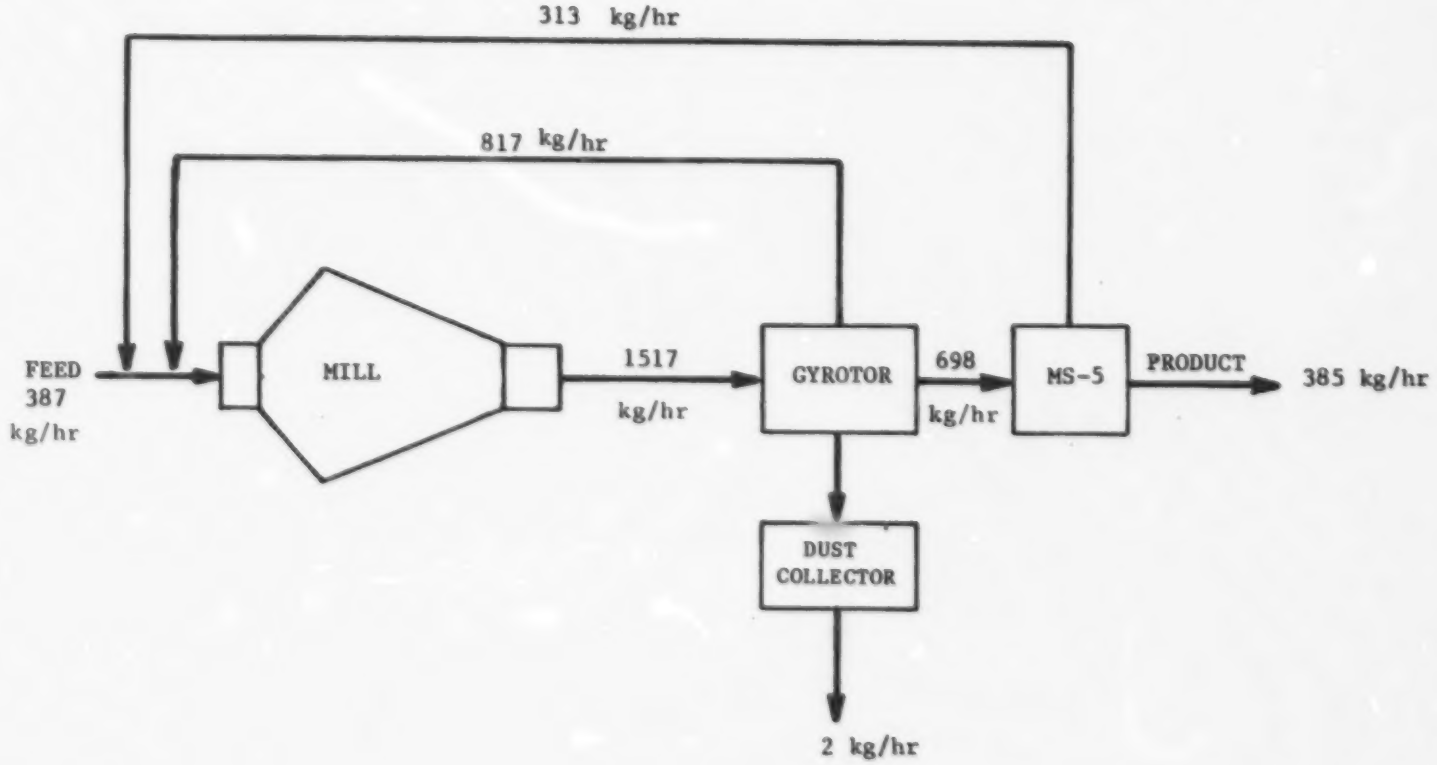
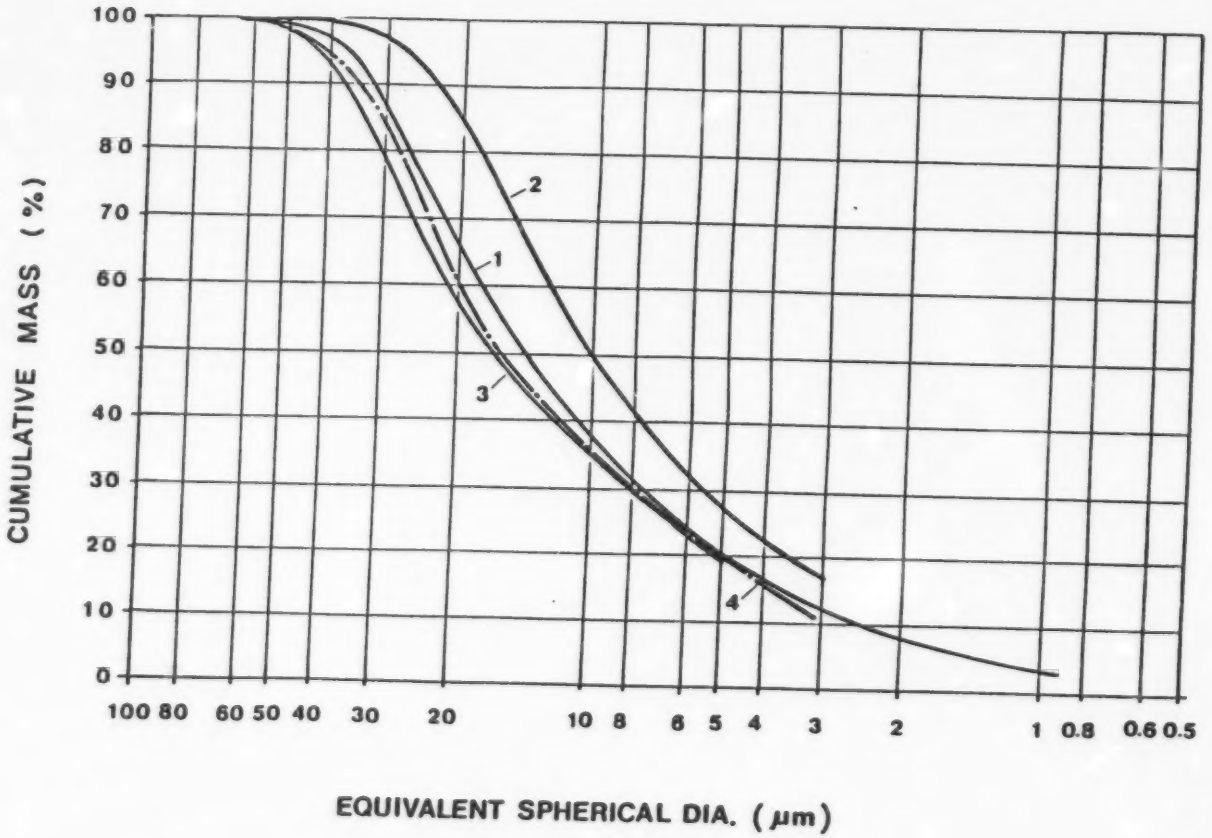


Figure 5.3-F2

PARTICLE SIZE DISTRIBUTION

TEST No.3 RUN No.1,2,3&4

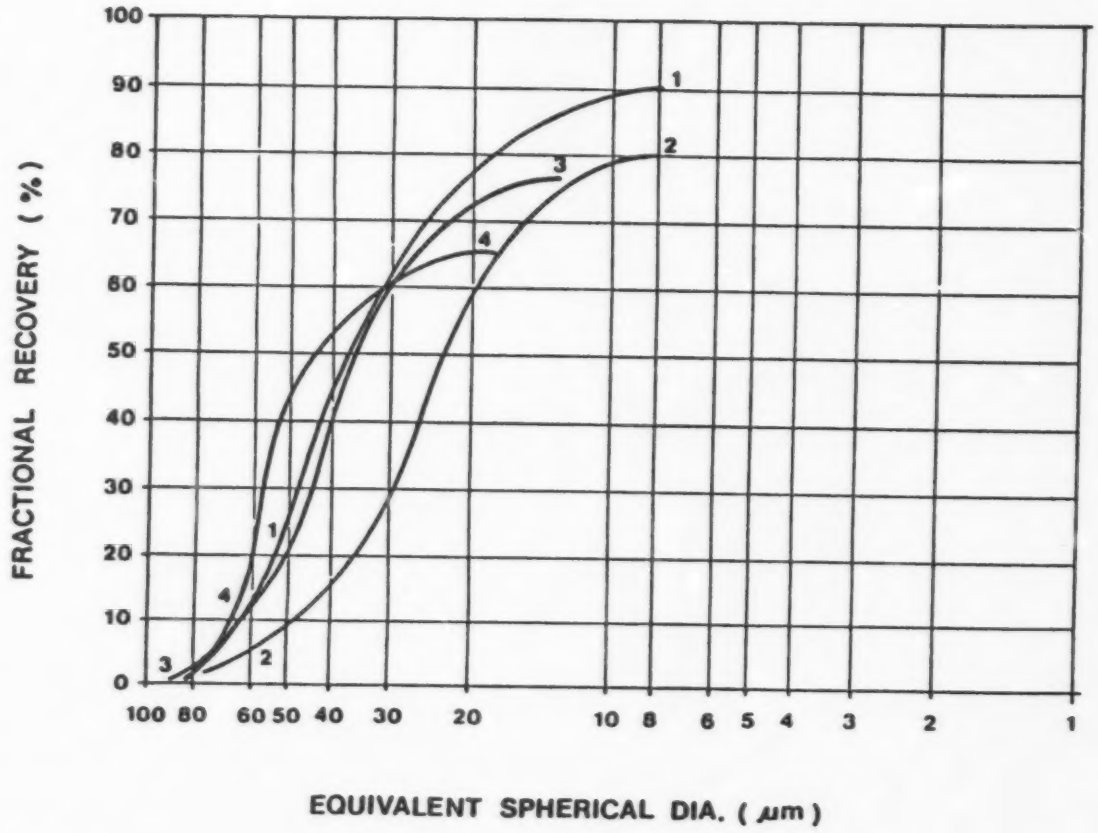


TROMP CURVE

TEST No. 3 RUN No.1,2,3&4

Figure 5.3-F3

PERCENT REPORTING TO UNDERSIZE
BOTH CLASSIFIERS OPERATING



5.4 Test 4

Test 4 was run to examine the performace of a high efficiency air classifier cleaning fines from the rejects of a conventional air classifier before returning them to the mill for regrinding. The flowsheet is illustrated in Figure 5.4-F1 and Operating Conditions presented in Table 5.4-T1.

Table 5.4-T1

TEST 4 OPERATING CONDITIONS

		Run		
		1	2	3
Nominal Feed Rate	(kg/hr)	400	400	385
Conventional Classifier				
- rotor speed	(rpm)	160	160	150
- rotor tip speed	(m/min)	460	460	457
High Efficiency Classifier				
- rotor speed	(rpm)	550	550	500
- classifier fan speed	(rpm)	4400	4400	4400
Air Temperature	(^{o}C)		37	34
Uptake Velocity	(m/min)		887	898

During Test 4, the objective was to make a final product containing 95-99% passing 45 microns from the conventional classifier, and a second product containing 95-99% passing 45 microns from the high efficiency classifier, using the conventional classifier oversize as feed. The measured and derived data are presented in Table 5.4-T2. The product particle size distribution is presented in Figure 5.4-F2.

A significant improvement in the production rate and classification efficiency was immediately achieved, as the amount of product (misplaced fines) being returned to the mill was reduced to less than 7%. The resulting high production rate, 92% higher than with the conventional classifier alone lowered the net power consumption by 27% over the conventional classifier, despite the extra motors in the circuit. Classification efficiency, as shown in Figure 5.4-F3 for the system exceeded 95% at 45 microns.

Table 5.4-T2

Test 4

		Runs 1	2	3
Measured Data				
Test period	hrs:min	2:12	1:54	1:47
Final product				
- total produced	kg	614	578	574
- product size	@ 45 microns	99.5	99	99
- product size	@ 10 microns	41	62	43
Dust collector				
- total produced	kg	4	2	4
- product size	@ 45 microns	100	100	100
Classifier returns				
- production rate	kg/hr	235	501	612
- product size	@ 325 mesh	28	28	28
High efficiency classifier returns				
- production rate	kg/hr	376	370	468
- product size	@ 325 mesh	4	3.5	6.5
Power consumed	kWh	63.6	55.7	47.3
Derived Data				
Production Rate				
- total	kg/hr	345	436	469
- minus 45 micron	kg/hr	337	429	461
Unit Power Consumption				
- total	kWh/tonne	83.9	67.1	56.5
- minus 45 micron	kWh/tonne	84.6	68.2	57.9
Circulating Load				
- classifier	%	-	-	-
- high eff. class.	%	-	-	-
- total	%	-	-	-
Efficiency				
- classifier	%	80.3	68.3	65.3
- high eff.class.	%	90.0	90.6	82.1
- overall	%	98.0	97.0	93.8

1016A

FIG. 54-F1

TEST 4

TYPICAL MATERIAL FLOW IN kg/hr

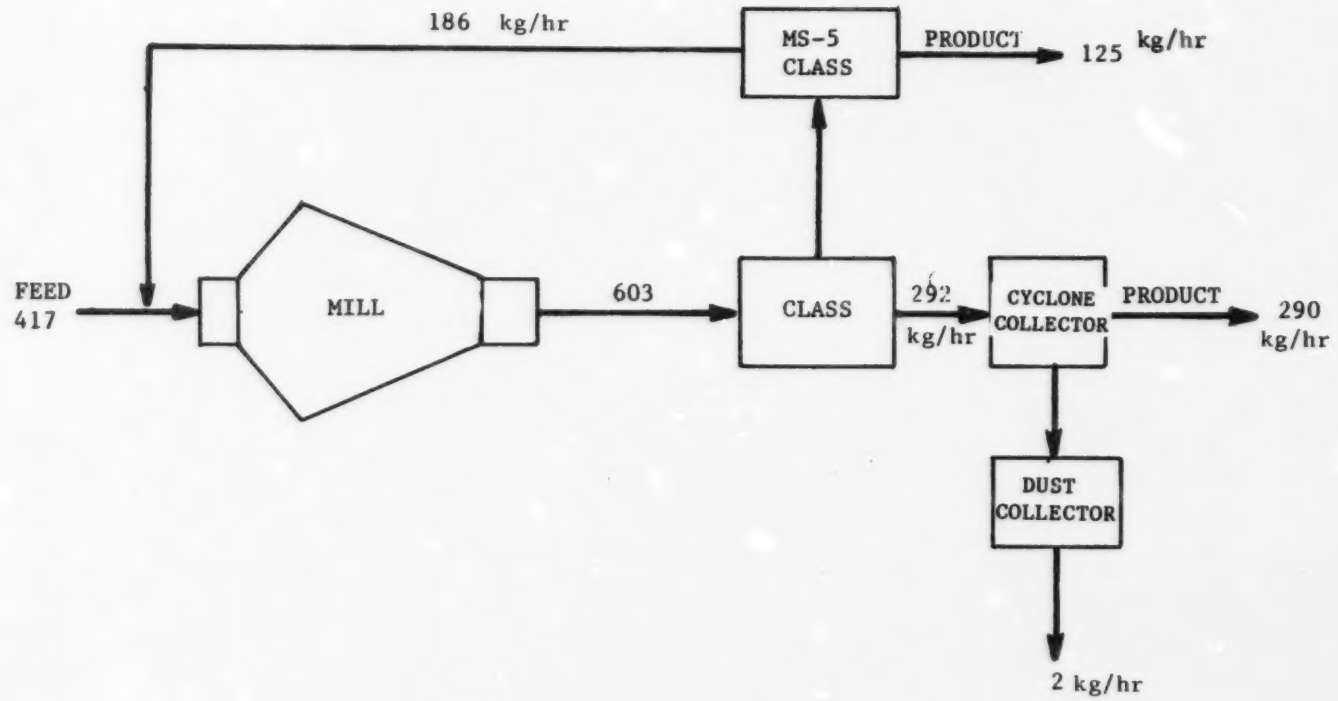
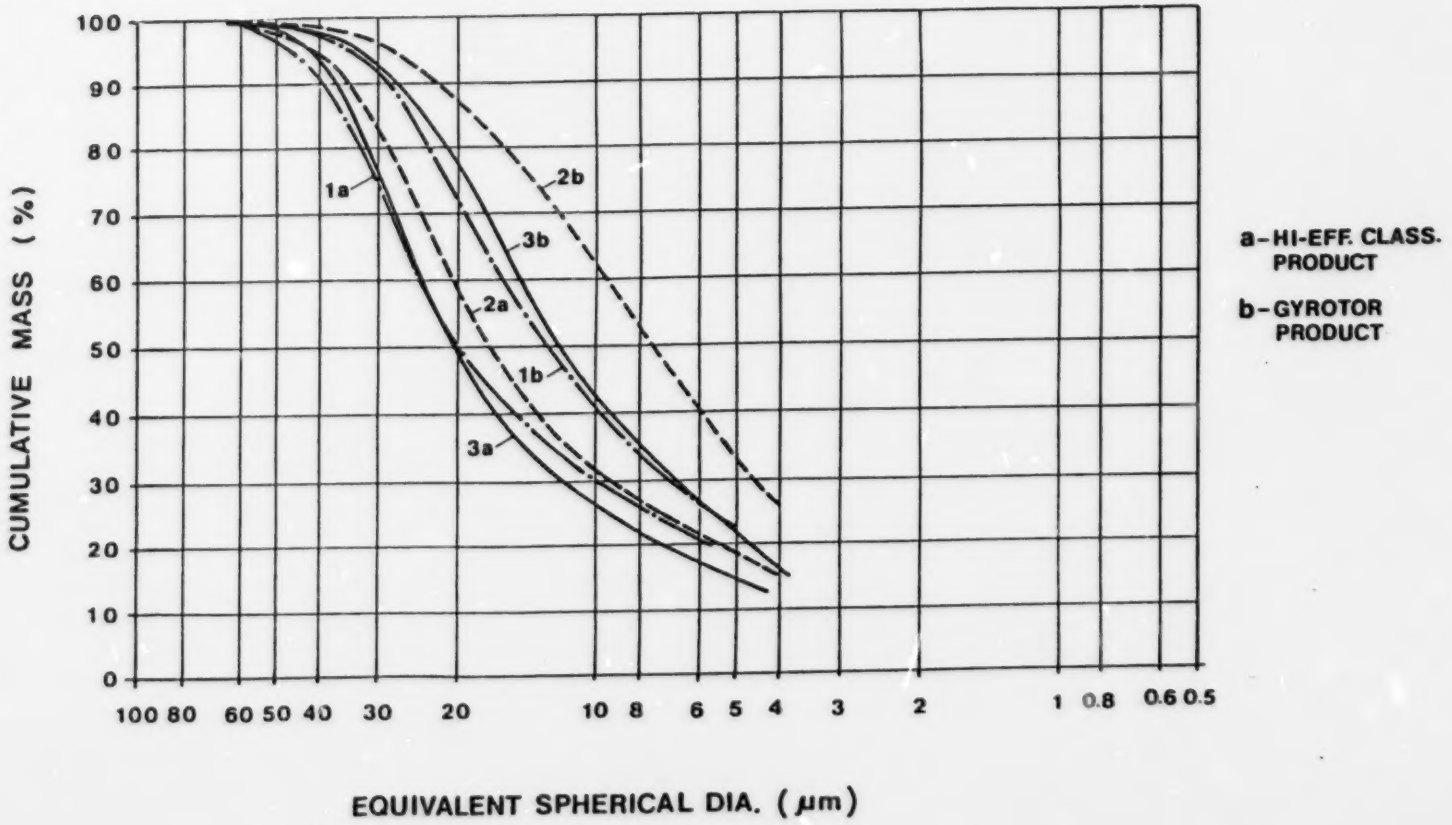


Figure 5.4-F2

PARTICLE SIZE DISTRIBUTION

TEST No.4 RUN No.1,2&3

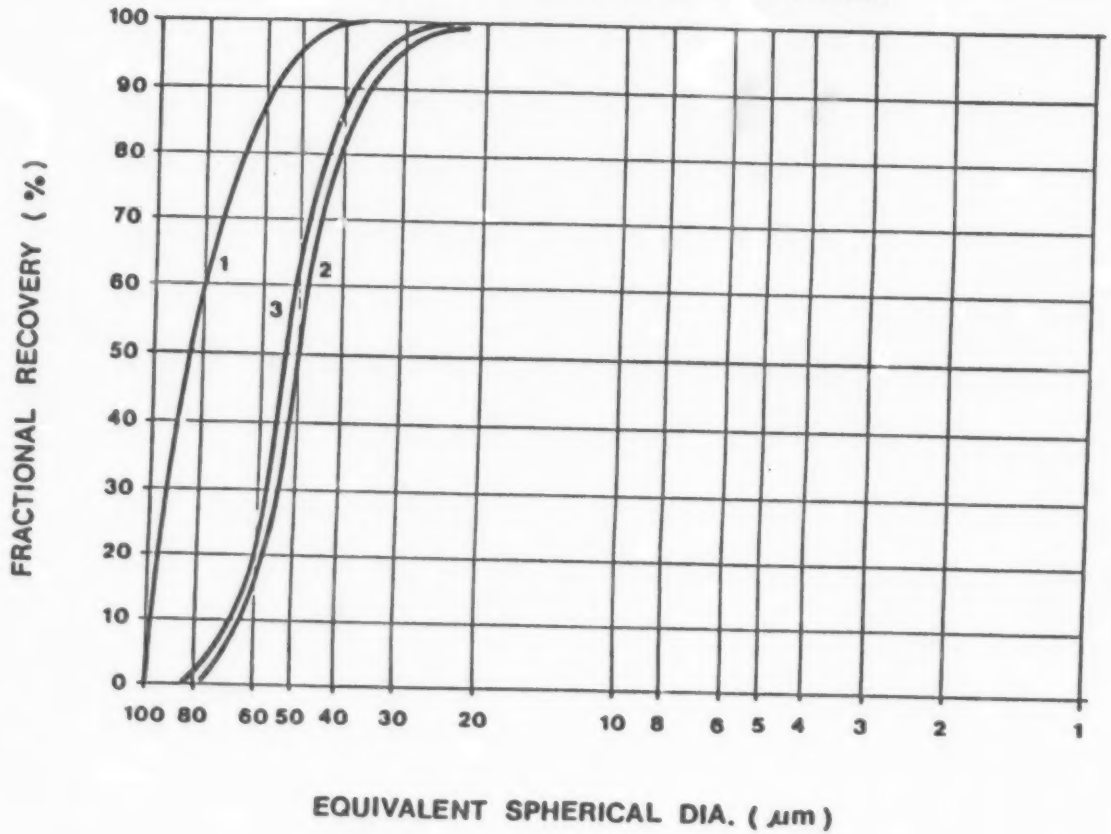


TROMP CURVE

Figure 5.4-F3

TEST No.4 RUN No.1,2&3

PERCENT REPORTING TO UNDERSIZE
BOTH CLASSIFIERS OPERATING



5.5 Test 5

Test 5 examined the performance of the grinding circuit producing progressively finer products. The dry grinding/classification circuit is illustrated in Figure 5.5-F1. Operating conditons for a 20 micron product are given in Table 5.5-T1. The measured and derived data are presented in Table 5.5-T2.

Table 5.5-T1

Test 5 - Operating Conditions

		Run			
		2	3	4	5
Nominal Feed Rate	kg/hr	227	182	91	182
Conventional Classifier					
rotor speed	rpm	335	180	180	290
rotor tip speed	m/sec	963	517	517	834
High Efficiency Classifier					
rotor speed	rpm	Variable	1400	1400	1400
classifier fan speed	rpm	4400	4400	4400	4400

The high efficiency classifier was operated at various rotor speeds to make a progressively finer product. The conventional classifier was operated to produce a 95-99% minus 45 micron feed to the high efficiency classifier. As expected, product rate decreased and the recirculating load increased at higher rotor settings. Energy consumption increased to 143 kWh/tonne to make a 30 micron product and to 181 kWh/tonne to make a 20 micron product, as compared to 74 kWh/tonne required to produce a 45 micron product. Production decreased to 160 kg/hr for a 30 micron product and 122 kg/hr for a 20 micron product, compared to a production rate of 375-400 kg/hr for a 45 micron product from the same classifier.

The classifier rejects at these higher speeds and settings were all 90-95% passing 45 microns. Since this may be used as a product, savings in energy can be achieved if the production of both products (oversize and undersize) are included in operating cost equations. The energy consumption versus product size for Test 5 is illustrated in Figure 5.5-F4.

The size distribution curves and Tromp curves are shown in Figure 5.5-F2 and 5.5-F3.

1016A

Table 5.5-T2

Test 5

		Runs 3	4	5
Measured Data				
Test period	hrs:min	1.48	3.39	2.04
Final product				
- total produced	kg	288	306	319
- product size	@ 20 microns	97	93	96
Dust collector				
- total produced	kg	6	12	6
- product size	@ 20 microns	100	100	100
Classifier returns				
- production rate	kg/hr	215	84	327
- product size	@ 325 mesh	15	11	14
High efficiency classifier returns				
- production rate	kg/hr	706	601	273
- product size	@ 325 mesh	40	24	23
Power consumed	kWh	51.5	104.0	58.9
Derived Data				
Production Rate				
- total	kg/hr	163	87	157
- minus 45 micron	kg/hr	158	81	151
Unit Power Consumption				
- total	kWh/tonne	175.2	327.2	181.0
- minus 45 micron	kWh/tonne	180.7	130.5	188.1
Circulating Load				
- classifier	%	-	-	-
- high eff. class.	%	-	-	-
- total	%	-	-	-
Efficiency				
- classifier	%	93.1	92.6	82.2
- high eff.class.	%	34.8	34.8	70.0
- overall	%	32.1	31.7	56.7

1016A

FIG. 5.5-F1

TEST 5

TYPICAL MATERIAL FLOW IN kg/hr

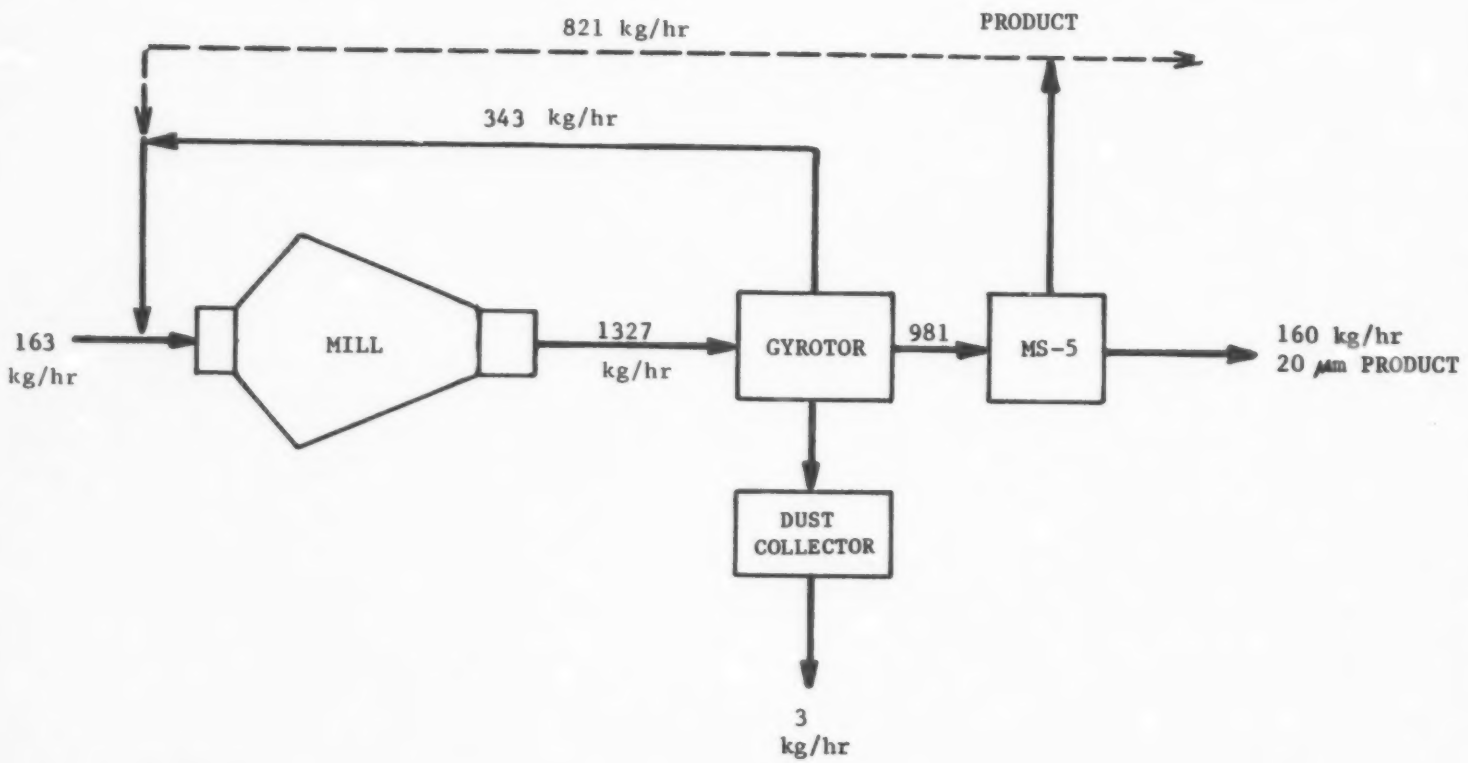


Figure 5.5-F2

PARTICLE SIZE DISTRIBUTION

TEST No.5 RUN No.3,4&5

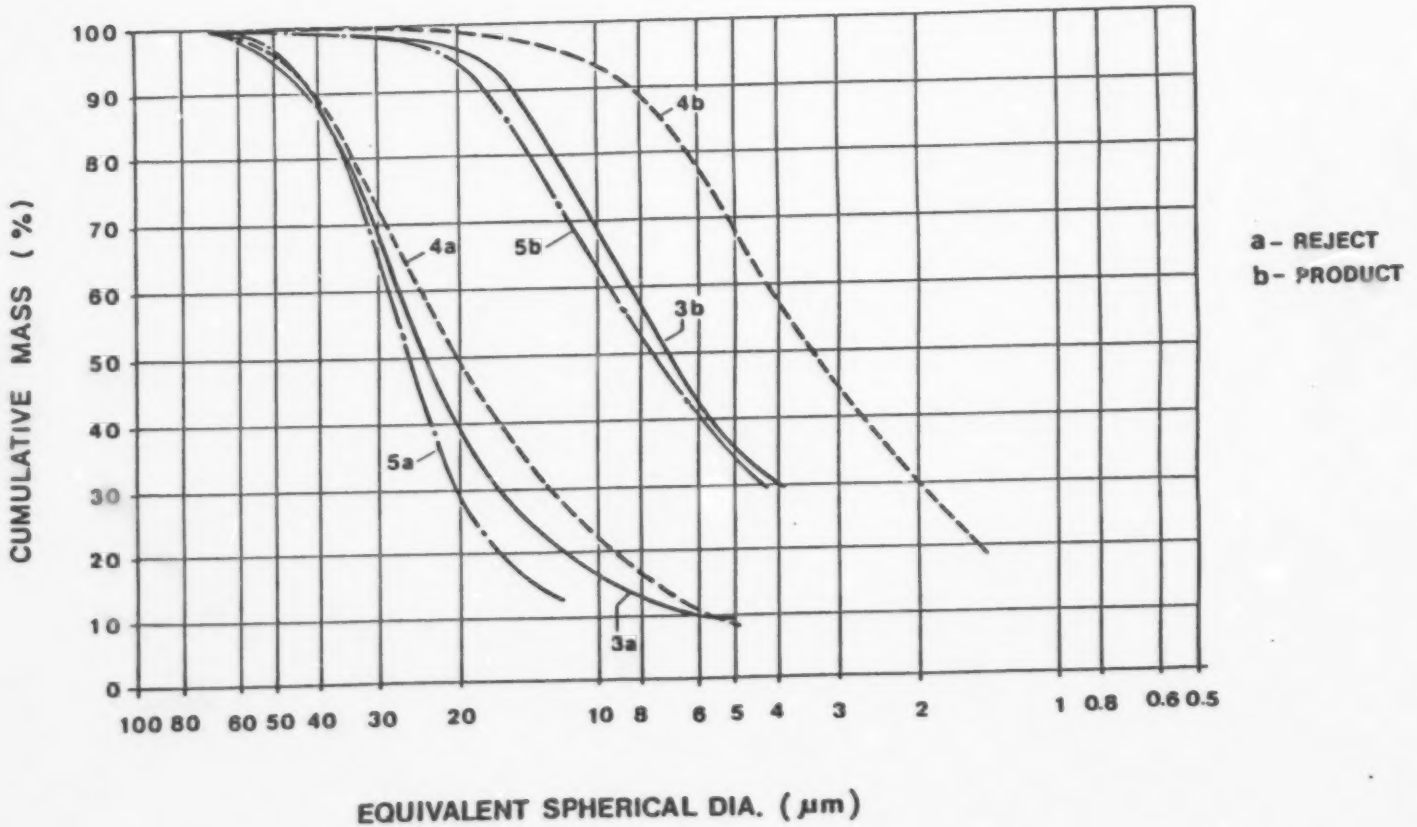


Figure 5.5-F3

TROMP CURVE

TEST No. 5 RUN No. 3,4 & 5

PERCENT REPORTING TO UNDERSIZE

HIGH EFF. CLASSIFIER

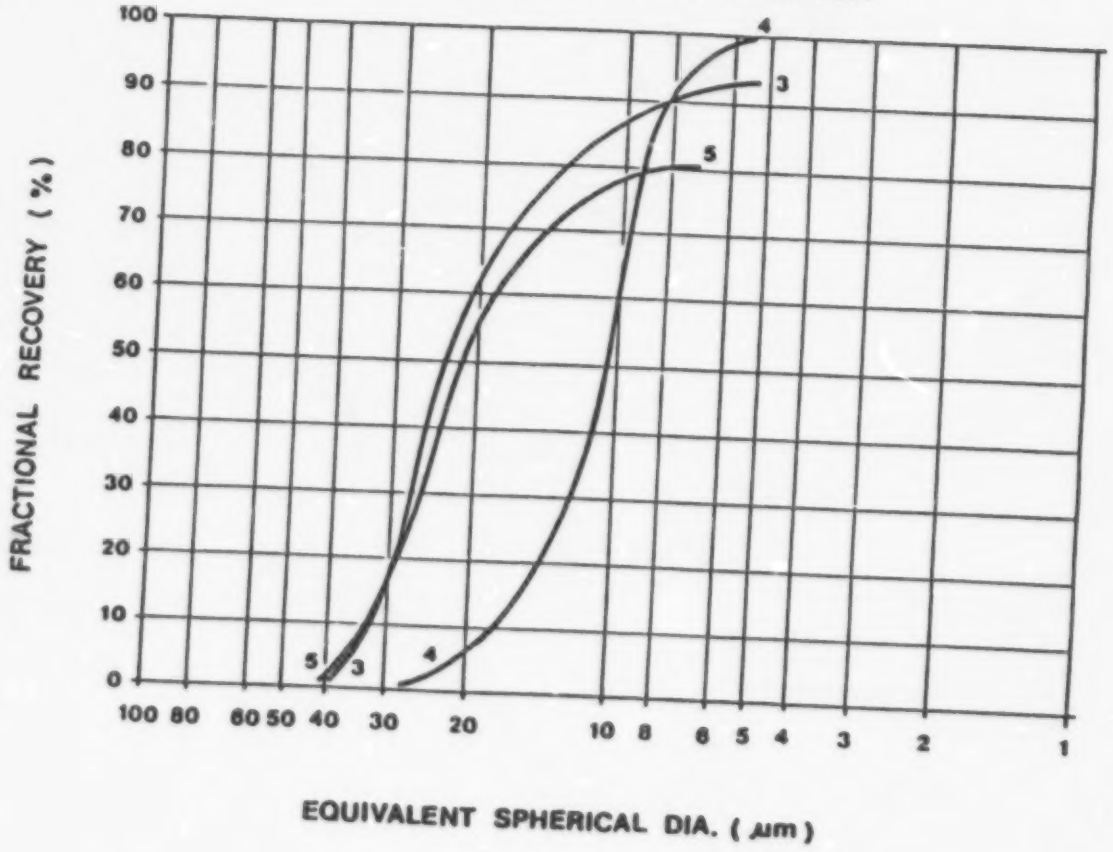
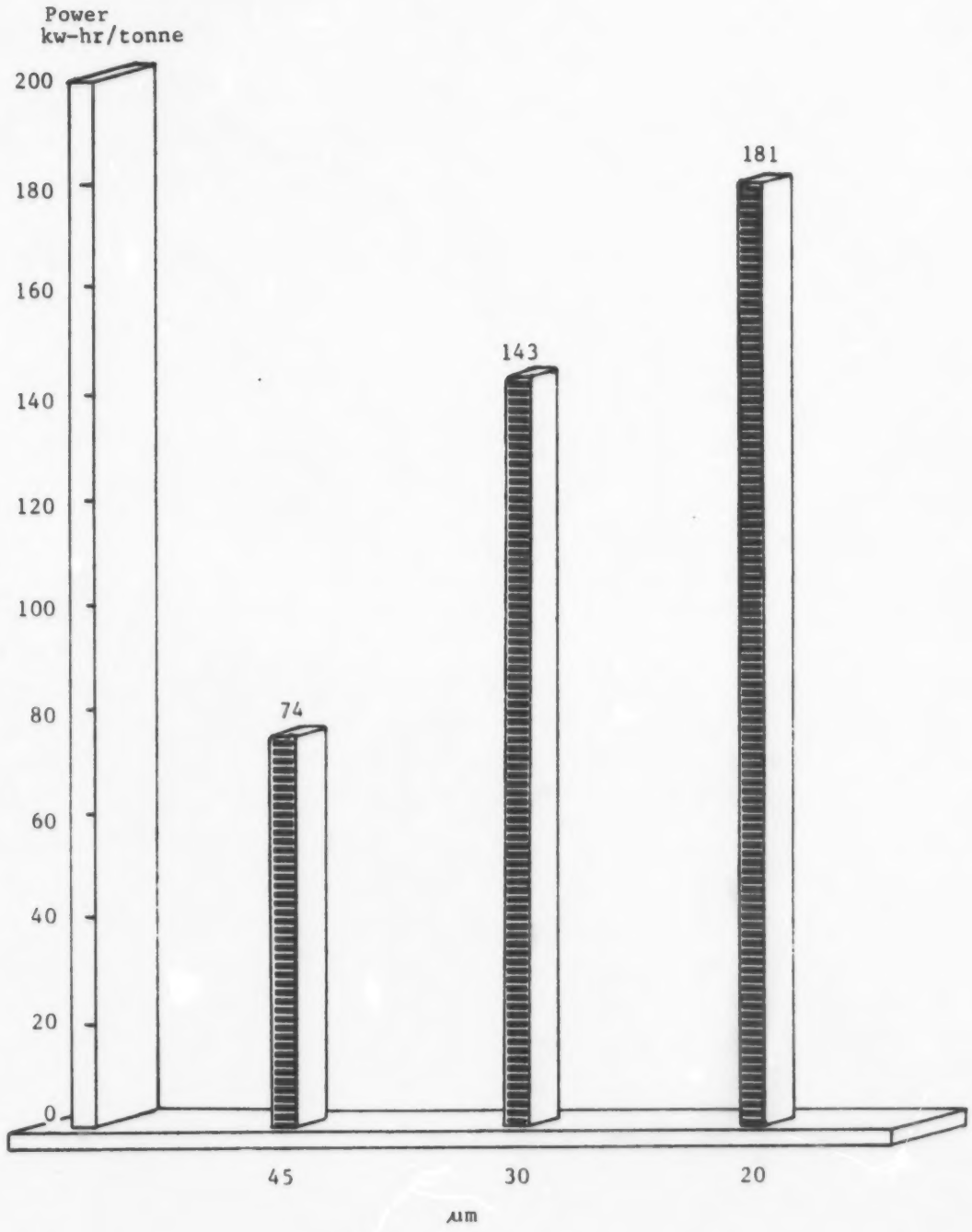


FIGURE: 5.5-F4

CANADA CEMENT LAFARGE

ACTIVITY:1

ENERGY CONSUMPTION VS PRODUCT SIZE



5.6 Dry Brightness

A comparison was made of the dry brightness of calcite ground with the Ni-hard steel grinding media, used in the pilot circuit and the same feed ground in a ceramic one gallon jar mill using high density fused alumina grinding media. The material was ground to 99% passing 325 mesh. Results of these tests indicate that the dry brightness of the steel ground calcite at 99% minus 325 mesh was only 0.1 to 0.4% darker than the ceramic ground calcite. This result is because of the use of Ni-hard balls in the mill. If softer steel media was used, the difference would likely have been larger. As brightness testing was not within the scope of this program, no further work was done. Further investigation into the effects of steel grinding versus ceramic on the dry brightness would be warranted.

6.0 CONCLUSIONS

Based on the pilot plant testing completed during Activity 1, the following conclusions have been determined:

1. The baseline pilot plant results accurately represent operating dry milling/classification circuits. The baseline data indicates the following:

   - Average kWhr/tonne 96
   - Classification efficiency 65%
   - Pilot plant production rate 213 lbs/hr

2. Replacing a conventional classifier with a properly sized high efficiency classifier (Test 2) may improve the following:

   - Average power savings in comminution 25%
   - Increase in classification efficiency 32%
   - Increase in production rate 74%

3. Utilizing a high efficiency classifier with an existing conventional classifier (Test 3) may improve the following:

   - Average power savings in comminution 25%
   - Increase in conventional classifier efficiency 18%
   - Increase in overall classification efficiency 7%
   - Increase in production rate 82%

4. Utilizing a high efficiency classifier with an existing conventional classifier (Test 4) may improve the following:

- Average power savings in comminution 27%
- Increase in conventional classifier efficiency 10%
- Increase in overall classification efficiency 48%
- Increase in production rate 92%

5. Utilizing a high efficiency classifier with an existing conventional classifier to produce a fine product (Test 5) may provide the following:

- Increase average in power consumption 75%
- Increase in gyrotor efficiency 89%
- Decrease in classification efficiency 38%
- Decrease in production rate 38%
- Circuit capable of producing two products.

6. Utilizing a high efficiency classifier in an existing circuit or by itself in a new milling circuit will:

- Use less power
- Require no additional operators or technical support staff.
- Increase production.
- Decrease operating costs.

7. Pilot plant testing is necessary to optimize a full scale grinding/classification circuit in order to properly identify all design criteria and maximize production requirements and maintain product quality.

1016A

APPENDIX I

TEST NO. 1B - DATA SHEETS

TEST NO. 1B

Set Variables		Run 1	Run 2
Nominal Feed Rate	lb/hr	500	600
Conventional Class			
- rotor speed	rpm	285	285
	fpm	2686	2686
High efficiency classifier			
- rotor speed	rpm	N/A	N/A
- aux. fan speed	rpm	N/A	N/A
Dependent Variables			
Air temperature	^{o}F	-	106
Uptake velocity	fpm	-	2149
Pressure differential across			
- fan	in. w.g.	16.7	16.6
- aspirator	in. w.g.	2.2	2.2
- classifier	in. w.g.	0.5	0.5
- cyclone	in. w.g.	3.2	3.2
Static pressure (to atmosphere)			
- fan intake	in. w.g.	-5.6	-5.7
- fan outlet	in. w.g.	+11.1	+10.9
- uptake	in. w.g.	-2.6	-2.7
- cyclone inlet	in. w.g.	-2.0	-
- cyclone outlet	in. w.g.	-5.4	-5.6
- dust collector	in. w.g.	+6.0	+5.0
Current measurements			
- fan	amps	19-21	18-20
- mill	amps	8.5	8.1
Measured Data			
Test period	hrs:min	5.48	4.59
Final product			
- total produced	lb	2849	2226
- product size	@ 45 m	2821	2204
Dust collector			
- total produced	lb	28	26
- product size	@ 45 m	100	100

Measured Data cont.		Run 1	Run 2
Classifier returns			
- production rate	lb/hr	904	1081
- product size	@ 325 m	24	28
High efficiency classifier returns			
- production rate	lb/hr	N/A	N/A
- product size	@ 325 m	N/A	N/A
Power consumed	kwhr	120.9	101.41
Derived Data			
Production Rate			
- total	lb/hr	496	452
- minus 45 μm	lb/hr	491	448
Unit Power Consumption			
- total	kwhr/s.ton	84.05	90.0
- minus 45μm	kwhr/s.ton	84.9	90.8
Circulating Loan			
- classifier	%	182	239
- high eff. class.	%	N/A	N/A
- total	%	N/A	N/A
Efficiency			
- classifier	%	69.3	59.7
- high eff.class.	%	N/A	N/A
- overall	%	N/A	N/A

APPENDIX II

TEST NO. 2 DATA SHEETS

OPERATING CONDITIONS — Test No. 2 — Run No.s 1-9 — Table 3

Set Variables		1	2	3	4	5	6	7	8	9
Nominal Feed-rate	- lb./hr	500	600	500	550	500 420	700	700	700	900
Conventional Classifier:										
- rotor speed	- rpm	-	-	-	-	-	-	-	-	-
	- fpm	-	-	-	-	-	-	-	-	-
High Efficiency Classifier:										
- rotor speed	- rpm	700	700	800	600	720	675	675	625	570
- aux. fan speed	- rpm	3700	3700	4400	4400	4400	4400	4400	4400	4400
Dependent Variables										
Air temperature	- ^{o}F	98.6								
Up-take air velocity	- fpm	3043								
Pressure Differential across:										
- fan	- in. w.g.	16.4	16.1	16.3	16.2	16.3	16.8	16.4	16.3	16.6
- aspirator	- in. w.g.	1.2	1.4	1.1	1.1	1.1	1.4	1.4	1.3	1.3
- classifier	- in. w.g.	-	-	-	-	-	-	-	-	-
- cyclone	- in. w.g.	2.7	2.8	2.5	2.0	2.0	2.7	2.2	2.0	2.0
Static Pressure (to atmosphere) at:										
- fan intake	- in. w.g.	-9.5	-9.8	-8.9	-7.0	-7.7	-8.3	-7.2	-8.0	-8.0
- fan outlet	- in. w.g.	+7.1	+6.5	+7.9	+9.3	+8.8	+8.3	+9.2	+8.3	+8.6
- uptake	- in. w.g.	-3.2	-3.6	-3.2	-3.6	-4.0	-3.4	-3.4	-3.0	-2.8
- cyclone inlet	- in. w.g.	-6.4	-6.9	-5.9	-5.2	-5.4	-6.2	-5.6	-6.0	-5.9
- cyclone outlet	- in. w.g.	-9.3	-9.6	-8.0	-6.8	-7.2	-8.8	-7.3	-7.9	-7.8
- dust collector	- in. w.g.	+5.2	+4.5	+5.8	+6.2	+6.1	+5.1	+5.8	+6.8	+6.0
Current Measurements:										
- fan	- amps	10.0	9.8	9.4	9.5	9.4	9.8	9.4	9.6	9.5
- mill	- amps									
- classifier	- amps	-	-	-	-	-	-	-	-	-
- high eff. classifier(rotor)	- amps	1.6	1.6	1.9	1.5	1.6	1.5	1.5	1.4	1.3

Test Results	Test No. 2	Run No.s 1 - 9								Table 4
Measured Data		1	2	3	4	5	6	7	8	9
Test Period	- hrs.:min.	1:45	2:00	3:00	2:55	2:50	1:36	1:12	2:01	1:24
Final Product:										
- total produced	- lb.	795	1018	1624	1608	1133	992.5	868	1541	1197
- product size	- % minus 45 microns	99.5	99.5	98.5	96.0	98.0	99.0	99.0	99.0	94.5
	- % minus 10 microns	43-45	44-49	44-48	36-41			46	39	29
Dust Collector:										
- total produced	- lb.	9	14	24	19	35	6.6	6.6	16.5	12
- product size	- % minus 45 microns	100	100	100	100	100	100	100	100	100
Classifier returns:										
- production rate	- lb./hr.	-	-	-	-	-	-	-	-	-
- product size	- % minus 325 - mesh	-	-	-	-	-	-	-	-	-
Hi-eff. classifier returns:										
- production rate	- lb./hr.	1597	2244	1448	656	551	930	1311	1471	1402
- product size	- % minus 325 - mesh	28.8	38.3	38.9	10.5	15.7	22.3	20.9	22.7	13.0
Power consumed	- kwh	42.2	47.2		76.3	76.7	45.2	31.7	54.2	38.4
Derived Data										
Production rate:										
- total	- lb./hr.	459	516	549	558	412	624	729	772	864
- minus 45 microns	- lb./hr.	457	513	541	536	404	618	722	765	817
Unit Power Consumption:										
- total	- kWh/s.ton	105.0	91.5		93.8	131.3	90.5	72.5	69.6	63.5
- minus 45 microns	- kWh/s.ton	105.5	91.9		97.7	133.9	91.4	73.2	70.3	67.2
Circulating load:										
- classifier	- %	-	-	-	-	-	-	-	-	-
- hi-eff. classifier	- %	347.6	434.9	263.6	117.6	133.7	148.9	179.9	190.5	162.4
- total	- %	-	-	-	-	-	-	-	-	-
Efficiency:										
- classifier	- %	-	-	-	-	-	-	-	-	-
- hi-eff. classifier	- %	50.0	37.5	49.4	89.0	82.7	75.1	72.7	69.8	82.6
- overall	- %	-	-	-	-	-	-	-	-	-

APPENDIX III

TEST NO. 3 DATA SHEETS

OPERATING CONDITIONS	Test No. 3	Run No.s 1-4		Table 5	
Set Variables		1	2	3	4
Nominal Feed-rate	- lb/hr	900	900	850	900
Conventional Classifier:					
- rotor speed	- rpm	160	160	150	150
	- fpm	1508	1508	1414	1414
High Efficiency Classifier:					
- rotor speed	- rpm	550	550	500	478
- aux. fan speed	- rpm	4400	4400	4400	4400
Dependent Variables					
Air temperature	- ^{o}F	91.4			
Up-take air velocity	- fpm	3062			
Pressure Differential across:					
- fan	- in. w.g.	16.1	16.1	16.2	16.2
- aspirator	- in. w.g.	1.8	2.0	1.4	3.1
- classifier	- in. w.g.	2.0	1.5	2.5	1.2
- cyclone	- in. w.g.	2.9	2.0	3.1	2.2
Static Pressure (to atmoshpere) at:					
- fan intake	- in. w.g.	-7.8	-6.5	-8.6	-7.2
- fan outlet	- in. w.g.	+8.2	+9.6	+7.8	+9.2
- uptake	- in. w.g.	-3.2	-3.2	-1.4	-4.1
- cyclone inlet	- in. w.g.	-5.0	-4.2	-5.2	-5.0
- cyclone outlet	- in. w.g.	-7.8	-6.4	-8.4	-7.1
- dust collector	- in. w.g.	+6.2	+7.4	+6.0	+6.2
Current Measurements:					
- fan	- amps	9.9	9.4	9.9	8.0
- mill	- amps	15-17	16-18	15-17	18-20
- classifier	- amps	1.4	1.5	1.5	1.5
- high eff. classifier (rotor)	- amps	1.2	1.2	1.2	1.1

WD1

Test Results	Test No. 3	Run No.s 1 - 4		Table 6	
Measured Data		1	2	3	4
Test Period	- hrs.:min.	1:28	2:00	1:45	1:57
Final Product:					
- total produced	- lb.	1208	1686	1517	1854
- product size	- % minus 45 microns	99	98	96	96
	- % minus 10 microns	42	49	35	36
Dust Collector:					
- total produced	- lb.	9	11.3	22	21
- product size	- % minus 45 microns	100	100	100	100
Classifier returns:					
- production rate	- lb./hr.	1254	3600	510	1680
- product size	- % minus 325 - mesh	17	17	14	23.4
Hi-eff. classifier returns:					
- production rate	- lb./hr.	856	551	663	949
- product size	- % minus 325 - mesh	16	16	12	12
Power consumed	- kwh	41.0	56.0	49.1	54.8
Derived Data					
Production rate:					
- total	- lb./hr.	830	849	879	962
- minus 45 microns	- lb./hr.	822	823	845	924
Unit Power Consumption:					
- total	- kWh/s.ton	67.4	66.0	63.8	58.5
- minus 45 microns	- kWh/s.ton	68.1	67.3	66.4	60.9
Circulating load:					
- classifier	- %	151.1	424.2	58.0	174.7
- hi-eff. classifier	- %	103.2	64.9	75.4	98.7
- total	- %	254.3	489.1	133.4	273.4
Efficiency:					
- classifier	- %	79.6	58.1	92.5	71.0
- hi-eff. classifier	- %	85.8	90.6	91.7	89.4
- overall	- %	70.3	54.8	85.4	65.5

APPENDIX IV

TEST NO. 4 DATA SHEETS

TEST NO. 4

		RUN NO 1-3		
		1	2	3
Set Variables				
Nominal Feed-rate	- lb./hr	700	1000	1100
Conventional Classifier:				
- rotor speed	- rpm	285	285	285
	- fpm	2686	2686	2686
High Efficienty Classifier:				
- rotor speed	- rpm	575	575	575
- aux fan speed	- rpm	4400	4400	4400
Dependent Variables				
Air Temperature	- ^{o}F	-	98.6	93.2
Up-take air velocity	- fpm	-	2910	2946
Pressure Differential across:				
- fan	- in. w.g.	16.8	16.8	17.0
- aspirator	- in. w.g.	1.4	1.5	1.6
- classifier	- in. w.g.	1.2	1.1	1.0
- cyclone	- in. w.g.	2.8	2.8	2.8
Static Pressure (to atmosphere) at:				
- fan intake	- in. w.g.	-6.5	-6.5	-6.6
- fan outlet	- in. w.g.	+10.2	+10.3	+10.7
- uptake	- in. w.g.	-2.5	-2.7	-2.5
- cyclone inlet	- in. w.g.	-3.4	-3.5	-3.8
- cyclone outlet	- in. w.g.	-6.2	-6.2	-6.5
- dust collector	- in. w.g.	+7.0	+7.0	+7.0
Current Measurements:				
- fan	- amps	8.8	8.8	8.8
- mill	- amps	20-21	19-21	20-22
- classifier	- amps	1.5	1.5	1.5
- high eff. classifier	- amps	8-9	8-9	9-10
- rotor	- amps	1.2	1.2	1.2

WD1

TEST RESULTS Test No. 4

Measured Data:

		1	2	3
Test Period	- hrs.:min.	2:12	1:54	1:47
Classifier Product				
- total Produced	- lb	1353	1275	1266
- product Size	- % minus 45 microns	99.5	99	99
	- % minus 10 microns	41	62	43
Hi-eff. Classifier Product				
- total Produced	- lb	311	549	567
- product Size	- % minus 45 microns	95.5	97	97
	- % minus 10 microns	31	32	21
Dust Collector:				
- total Produced	- lb	8	5	9
- product Size	- % minus 45 microns	100	100	100
Classifier Returns:				
- production Rate	- lb/hr	519	1104	1349
- product Size	- % minus 325 - mesh	28	28	28
Hi-efficient Classifier Returns:				
- production Rate	- lb/hr	830	815	1031
- product Size	- % minus 325 - mesh	4	3.5	6.5
Power Consumed	- kwh	63.6	55.7	47.3

WD1

Derived Data:

		1	2	3
Production Rate:				
- total	- lb./hr	760	962	1033
- minus 45 microns		744	946	1016
Unit Power Consumption:				
- total	- kWh/s.ton	76.1	60.9	51.3
- minus 45 microns	-kWh/s. ton	76.8	61.9	52.2
Efficiency:				
- classifier	- %	80.3	68.3	65.3
- hi-eff.	- %	90.0	90.6	82.1
- overall	- %	98.0	97.0	93.8

APPENDIX V

TEST NO. 5 DATA SHEETS

OPERATING CONDITIONS | Test No. 5 | Run 1 | Table 7

Set Variables		A	B	C	D	E
Nominal Feed-rate	- lb./hr	500	500	500	550	500
Conventional Classifier:						
- rotor speed	- rpm	335	335	335	335	335
	- fpm	3157	3157	3157	3157	3157
High Efficiency Classifier:						
- rotor speed	- rpm	1200				
- aux. fan speed	- rpm	4400				
Dependent Variables						
Air temperature	- ^{o}F	118	118	118	118	188
Up-take air velocity	- fpm	3304	3304	3304	3304	3304
Pressure Differential across:						
- fan	- in. w.g.	16.0	16.0	15.9	15.8	15.8
- aspirator	- in. w.g.	1.4	1.4	1.6	1.8	1.8
- classifier	- in. w.g.	1.3	1.3	1.2	1.3	1.2
- cyclone	- in. w.g.	2.8	2.9	2.8	2.9	2.9
Static Pressure (to atmosphere) at:						
- fan intake	- in. w.g.	-6.8	-6.5	-6.5	-6.7	-6.8
- fan outlet	- in. w.g.	+9.4	+9.4	+9.4	+9.2	+9.2
- uptake	- in. w.g.	-2.6	-2.6	-2.4	-2.7	-2.7
- cyclone inlet	- in. w.g.	-3.7	-3.8	-3.7	-3.8	-4.0
- cyclone outlet	- in. w.g.	-6.5	-6.6	-6.6	-6.7	-6.7
- dust collector	- in. w.g.					
Current Measurements:						
- fan	- amps	8.1	8.2	8.2	8.2	8.1
- mill	- amps	19-21	19-21	19-21	19-21	18-20
- classifier	- amps	1.6	1.6	1.6	1.6	1.6
- high eff. classifier(rotor)	- amps	2.2	2.8	3.2	2.6	2.3

WD1

TEST RESULTS | Test No. 5 | Run 1 | Table 8

Measured Data		A	B	C	D	E	TOTAL
Test Period	- minutes	15	15	15	15	15	75
Final Products:							
- oversize product	- total produced, lb.	39.0	68.0	71.0	84.5	82.5	345.0
	- 98% passing, microns	52	52	41	43	48	-
	- 30% passing, microns	18	19	11	12	13	-
- undersize product	- total produced, lb.	83.0	64.0	57.5	50.0	44.5	299.0
	- 98% passing, microns	23	20	16	15	16	-
	- 30% passing, microns	3.7	2.9	2.6	2.4	2.5	-
- dust	- total produced, lb.	-	-	-	-	-	11.0
Classifier returns:							
- production rate	- lb./hr.	1040	1320	1200	1080	-	
Power consumed	- kwh	6.7	7.1	7.0	7.2	6.4	34.4
Derived Data							
Production rate:							
- total	- lb./hr.	(497)	(537)	(523)	(547)	(517)	524
- cleaned product	- lb./hr.	156	272	284	338	330	-
- fines	- lb./hr.	332	256	230	200	178	-
- dust	- lb./hr.	(9)	(9)	(9)	(9)	(9)	9
Net Power Consumption:							
- total	- kWh/s.ton	107.8	105.8	107.1	105.3	99.0	105.0
- cleaned product	- kWh/s.ton	497.2	208.8	197.2	170.4	155.2	-
- fines	- kWh/s.ton	161.4	221.9	243.5	288.0	287.6	-
Circulating load:							
- classifier	- %	209	246	229	197	-	-

TEST NO. 5

		RUN NO 2	3	4	5	6
Set Variables						
Nominal Feed-rate	- lb./hr	500	400	200	400	500
Conventional Classifier:						
- rotor speed	- rpm	170	180	180	290	306
	- fpm	1602	1696	1696	2733	2884
High Efficienty Classifier:						
- rotor speed	- rpm	1100	1400	1400	1400	1400
- aux fan speed	- rpm	4400	4400	4400	4400	4400
Dependent Variables						
Air Temperature	- ^{o}F	118				
Up-take air velocity	- fpm	3304				
Pressure Differential across:						
- fan	- in. w.g.	16.8	16.2	16.4	16.1	16.0
- aspirator	- in. w.g.	2.5	2.1	2.1	1.8	2.5
- classifier	- in. w.g.	1.9	1.9	1.5	1.4	1.8
- cyclone	- in. w.g.	3.5	3.3	3.4	3.5	3.5
Static Pressure (to atmosphere) at:						
- fan intake	- in. w.g.	-9.0	-8.9	-9.2	-8.5	-9.2
- fan outlet	- in. w.g.	+7.2	+7.2	+7.2	+7.5	+6.8
- uptake	- in. w.g.	-4.2	-3.6	-2.9	-3.5	-3.9
- cyclone inlet	- in. w.g.	-5.9	-5.5	-5.4	-5.0	-5.7
- cyclone outlet	- in. w.g.	-9.5	-8.8	-8.7	-8.5	-9.2
- dust collector	- in. w.g.	+5.2	+6.0	+5.1	+5.2	+5.2
Current Measurements:						
- fan	- amps	8.7	8.9	9.0	8.7	8.8
- mill	- amps	19-21	19-21	19-21	19-21	19-21
- classifier	- amps	1.5	1.4	1.5	1.5	1.5
- high eff. Classifier	- amps	7-9	7-9	7-9	8-9	7-9
- rotor	- amps	2.1	2.6	2.3	2.3	2.3

WD1

TEST RESULTS Test No. 5

Measured Data

		2	3	4	5	6
Test Period	- hrs:min	1.42	1.48	3.39	2.04	1.00
Product size	- microns	30	20	20	20	20
Total Product:						
- total produced	- lb.	764	634	675	704	425
- product size	- % passing	98	97	93	96	98
Dust Collector:						
- total produced	- lb.	14	14	27	14	7
- product size	- % passing	100	100	100	100	100
Classifier Returns						
- production rate	- lb/hr	860	474	185	720	910
- product size	- % passing	14	15	11	14	24
Hi-eff. Classifier Returns:						
- production Rate	- lb/hr	1359	1557	1324	602	2182
- product Size	- % passing	41	40	24	23	82
Power Consumed	- kwh	49.4	51.5	104.0	58.9	28.0

WD1

Derived Data:

		2	3	4	5	6
Production Rate:						
- total	- lb./hr.	457	360	192	347	432
- products	- lb./hr.	448	349	179	334	424
Unit Power Consumption:						
- Total	- kWh/s.ton	127.1	158.9	296.8	164.2	129.6
- products	- kWh/s.ton	129.7	163.9	318.4	170.6	132.3
Efficiency:						
- classifier	- %	89.3	93.1	92.6	82.2	72.1
- hi-efficient classifier	-%	44.2	34.8	34.8	70.0	35.8
- overall	-%	39.2	32.1	31.7	56.7	25.7

WD1